

WL-TR-94-3133

ADVANCED FIRE SUPPRESSION  
TECHNOLOGY (AFST) RESEARCH AND DEVELOPMENT  
PROGRAM



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SEPTEMBER 1994

INTERIM REPORT FOR 09/15/93-09/15/94

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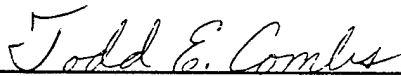
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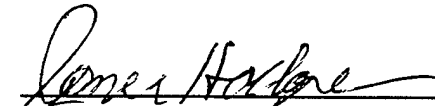
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Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE SEP 1994		3. REPORT TYPE AND DATES COVERED INTERIM 09/15/93 - 09/15/94
4. TITLE AND SUBTITLE ADVANCED FIRE SUPPRESSION TECHNOLOGY (AFST) RESEARCH AND DEVELOPMENT			5. FUNDING NUMBERS C F33615-93-C-3404 PE 62201 PR 2402 TA 02 WU TU	
6. AUTHOR(S) ROBERT M. (MITCH) MITCHELL				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) OLIN AEROSPACE COMPANY 11441 WILLOWS ROAD N.E. P.O. BOX 97009 REDMOND WASHINGTON 98073-9709			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) FLIGHT DYNAMICS DIRECTORATE WRIGHT LABORATORY AIR FORCE MATERIEL COMMAND WRIGHT PATTERSON AFB OH 45433-7562			10. SPONSORING/MONITORING AGENCY REPORT NUMBER WL-TR-94-3133	
11. SUPPLEMENTARY NOTES				
12A. DISTRIBUTION / AVAILABILITY STATEMENT  APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED			12.b. DISTRIBUTION CODE	
13. ABSTRACT  THE ADVANCED FIRE SUSPPRESSION TECHNOLOGY (AFST) RESEARCH AND DEVELOPMENT PROGRAM IS BEING CONDUCTED BY OLIN AEROSPACE COMPANY FOR WPAFB. THE THREE PHASE PROGRAM GOAL IS TO EVALUATE THE FFECTIVENESS OF GAS GENERATOR TECHNOLOGY IN SUPPRESSING AIRCRAFT DRYBAY AND ENGINE NACELLE FIRES. THIS REPORT PRESENTS THE ACTIVITIES OF PHASE 1, INCLUDING AN INITIAL EVALUATION OF FILTERED AND NON-FILTERED SOLID PROPELLANT GAS GENERATORS, AS WELL AS SELECT HYBRID AGENTS.  <b>DTIC QUALITY INSPECTED 3</b>				
14. SUBJECT TERMS DRY BAY, ENGINE NACELLE, ADVANCED FIRE SUPPRESSION, AIRBAG, SOLID PROPELLANT			15. NUMBER OF PAGES 38	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

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## FOREWORD

Halon-1301, the chemical used for on-board fire suppression on military and commercial aircraft, will have production discontinued in 1994 due to its ozone depleting characteristics. The new Air Force official policy is to bank existing Halon for essential use until a replacement can be found and implemented, which is expected at the end of the decade. Unfortunately, most replacement chemicals currently under evaluation require up to three times the system weight and volume for equivalent protection, resulting in significant retrofit costs, reduced payload capacity and higher fuel usage.

Solid propellant systems, such as those used in automobile airbags shown in Figure 1, have been identified as a Halon-1301 alternative. Using advanced nonazide propellant technology, these systems can produce conventional fire suppression gases such as nitrogen, carbon dioxide and water vapor at high temperatures which render them effective in comparison to Halon-1301. Figure 2 depicts the operational mode of a solid propellant gas generator. Upon receipt of an appropriate electrical signal, an electrical initiator functions inside the gas generator, providing pressure, heat and hot particles which ignites the solid propellant grain. The propellant begins generating gas at its combustion temperature ( $> 2000^{\circ}\text{F}$ ) which results in rapid pressurization of the gas generator. At a predetermined pressure, a sealed burst disk ruptures, allowing gas to begin flowing out of the gas generator into the atmosphere which may be a sealed tank for characterization or a vented drybay to suppress a fire. The gas generator pressure profile is controlled by the ratio of the burning propellant surface area to the orifice flow area. An optional filter can be incorporated to cleanse the gas of any particulate evolved by the combustion process. The filter also reduces the propellant exhaust gas temperature due to its high surface area in contact with the propellant gas.

Hybrid gas generators shown in Figure 3 have also been identified as a Halon-1301 alternative. An operational schematic is illustrated in Figure 4. The hybrid gas generator consists of a solid propellant gas generator which discharges into a solid, liquid or vapor agent. The agent is pressurized and heated to a liquid or vapor state and then discharged at a predetermined pressure via a burst disk. The gas temperature of a hybrid gas generator is significantly cooler than that of a solid propellant-only gas generator due to the heat capacity of the hybrid agent. The hybrid system allows many agents to be evaluated as a halon alternative previously discounted due to their poor distribution properties. Possible candidates as a hybrid agent include:

- |  |                                       |
|--|---------------------------------------|
| 1) Water ( $\text{H}_2\text{O}$ )        | 3) FM-200 ( $\text{C}_3\text{HF}_7$ ) |
| 2) PFC-614 ( $\text{C}_6\text{F}_{14}$ ) | 4) Carbon dioxide ( $\text{CO}_2$ )   |

Most individuals familiar with the fire suppression industry are familiar with the basic mechanisms of extinguishing a fire. The basic mechanisms are:

- 1) Chemical (breaks chain reaction)
- 2) Oxygen depletion (dilution, smothering)
- 3) Thermodynamic (heat removal)



Figure 1  
Nonazide Passenger Side Inflator

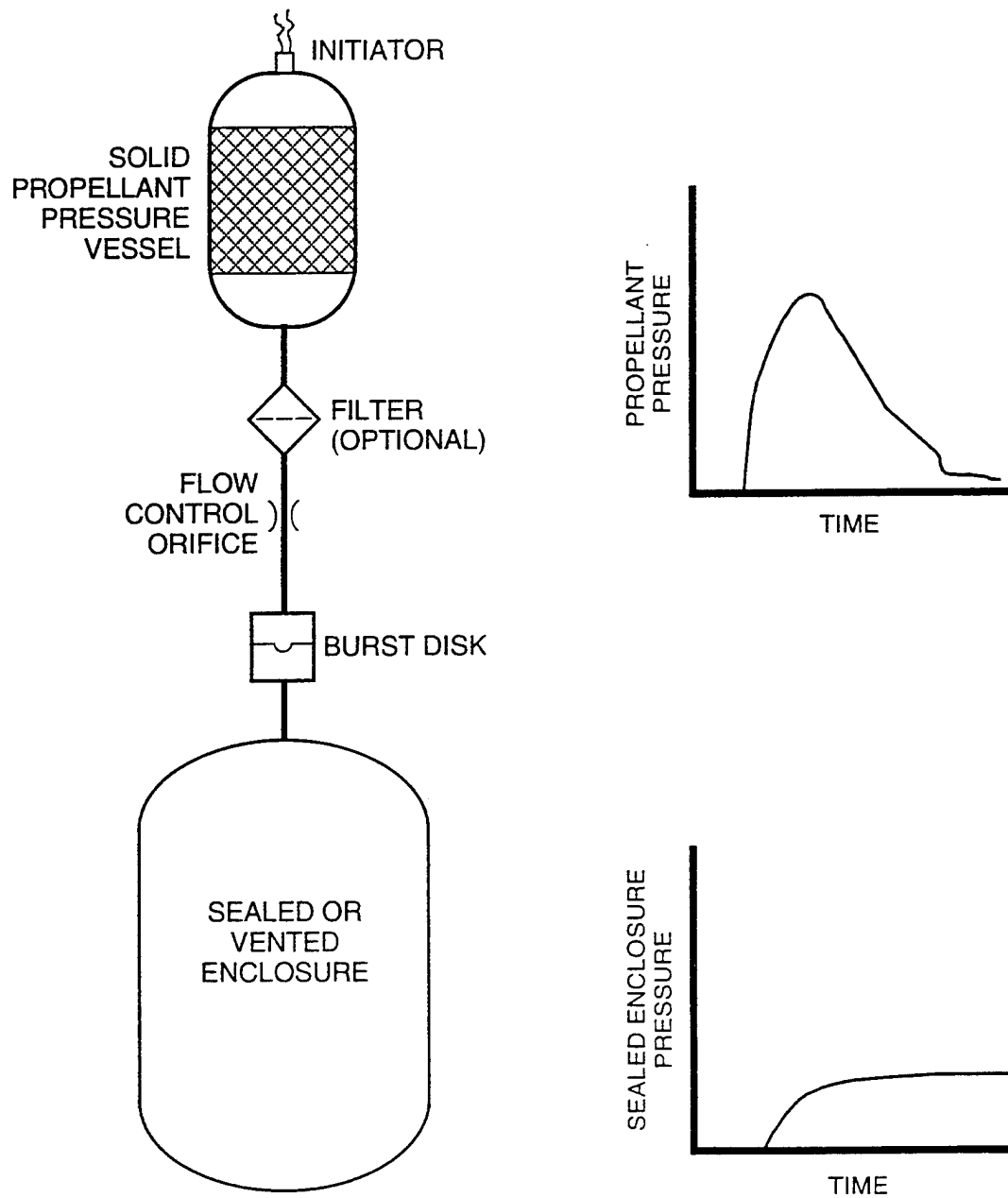


Figure 2  
Operational Schematic of Solid Propellant Gas Generator



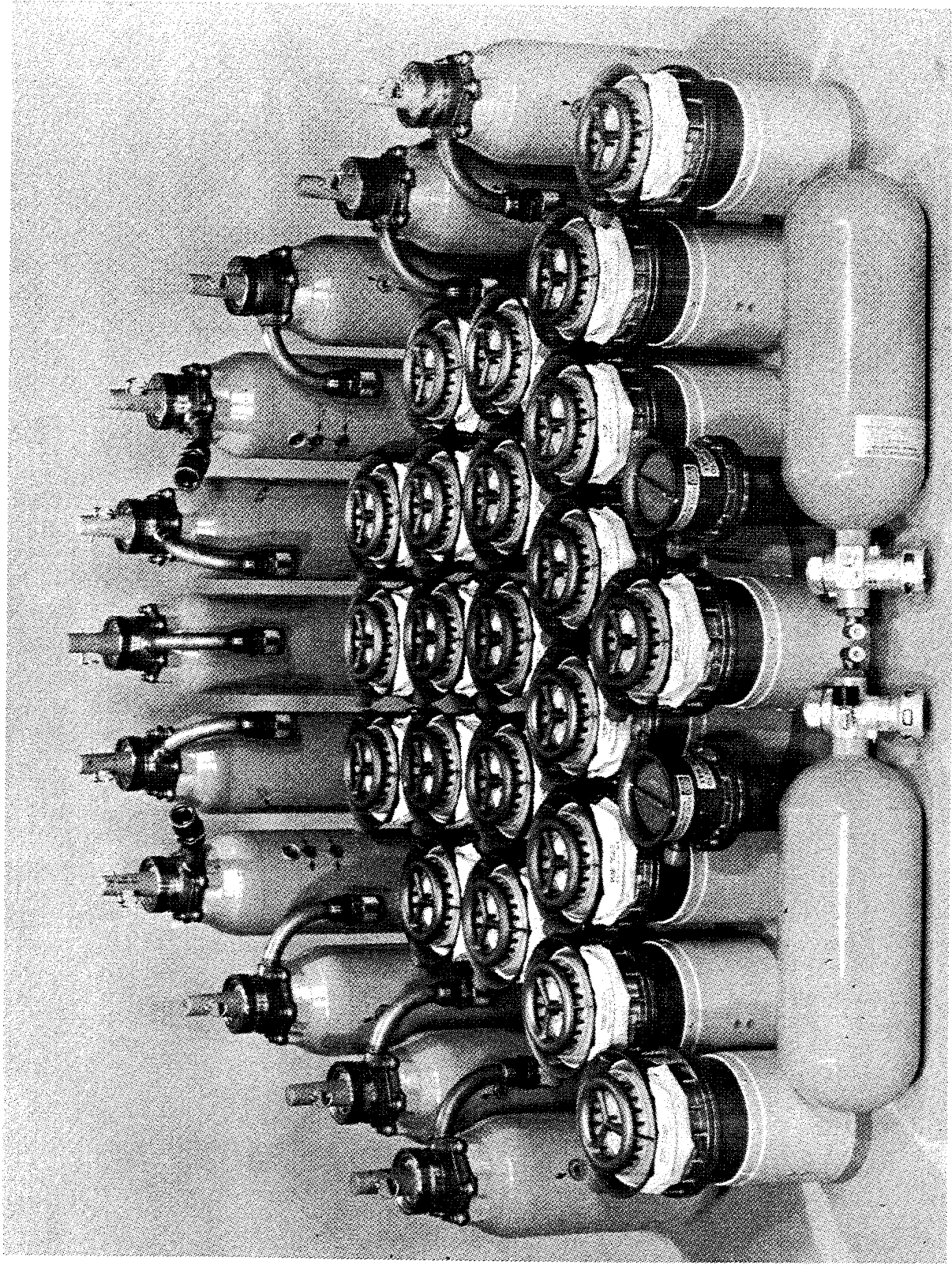


Figure 3  
747 Shipset of Slide Inflation Systems

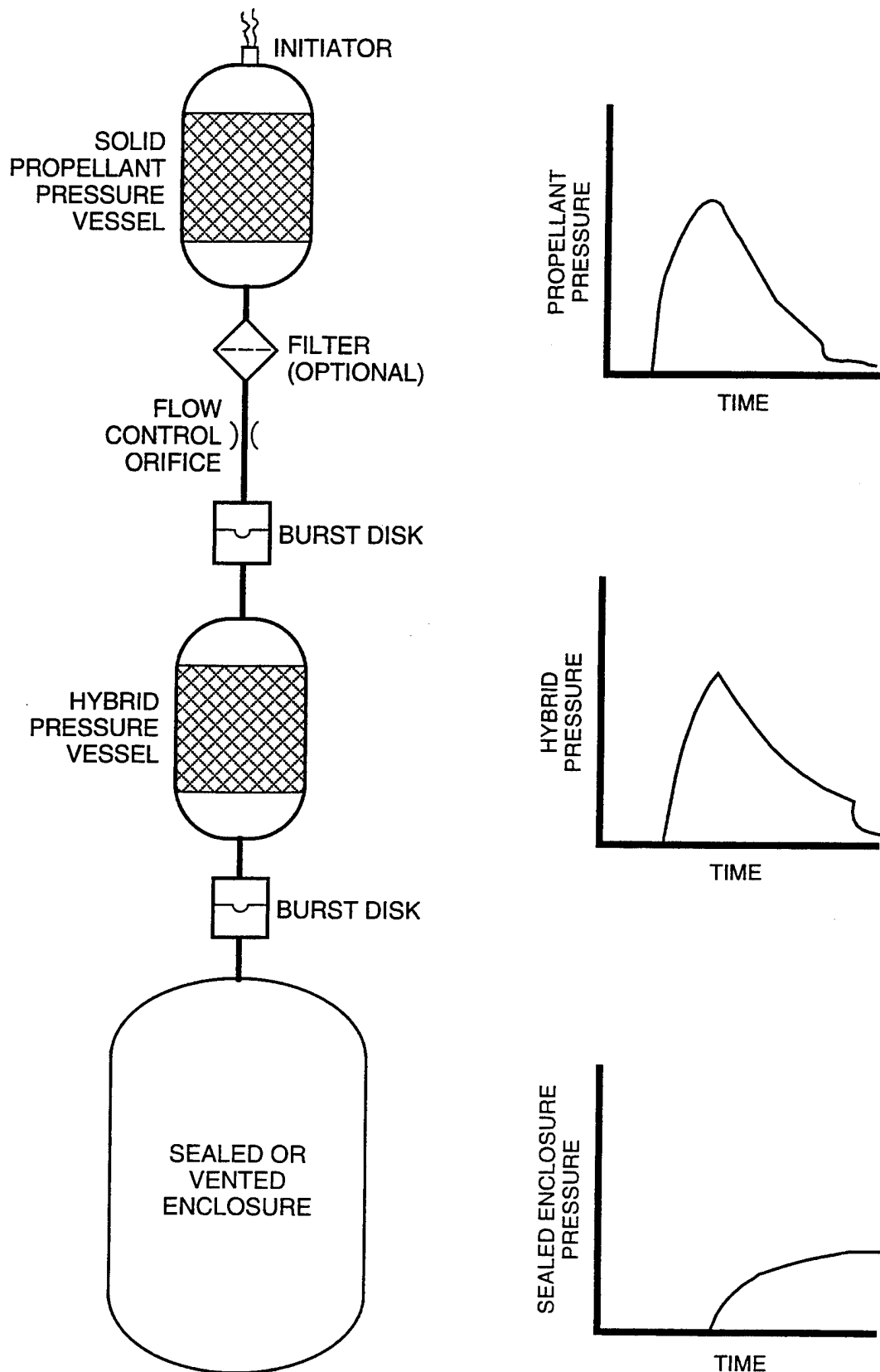


Figure 4  
Operational Schematic of Hybrid Gas Generator

Halon-1301 is such an effective agent due to its nature to chemically react with the radicals in the chain reaction. However, as illustrated in Table 1, the ozone depletion potential (ODP) of Halon-1301 is very high in comparison to other iodine, bromide, or chlorine containing compounds. Table 1 summarizes the specific heat capacity ( $C_p$ ) and molecular weight ( $mw$ ) of many potential halon-replacement/alternative agents. An ideal agent would have the highest  $C_p$  and lowest  $mw$  as possible. Helium meets this requirement very well, however, its storage requirements would negate any agent weight advantage. Water, carbon dioxide and nitrogen all have a relatively high  $C_p$  and low  $mw$  as compared to other agents. Therefore, the basic exhaust constituents of OAC nonazide propellants should be ideal fire suppressants. Table 1 also indicates that water or carbon dioxide make an ideal hybrid agent thermodynamically. Traditional use of carbon dioxide as a fire suppressant resulted in poor performance because up to 1/3 of the agent solidifies in the bottle. OAC's hybrid approach eliminates this problem with carbon dioxide by providing enough heat to vaporize and expel the agent. Figure 5 plots agent heat capacity per volume suppressed ( $1 \times 10^{-3}$  Btu/Ft<sup>3</sup> °R) as a function of agent concentration in percent (%). The agent concentration is based upon cup burner data widely used in the fire suppression industry. Oxygen concentration in percent is also provided. Figure 5 shows the effectiveness that the addition of a chemical reactor (I, Br, Cl) has on agent concentration and total agent heat capacity. Clearly, the iodines and bromides exhibit a significant chemical reaction with the chlorines only slightly reactive. The fluorines are not reactive at all; having approximately the same heat capacity as nitrogen, helium and water. Note that oxygen content appears to not be a significant factor except for Argon (Ar). There is discussions within the industry that suggests that an oxygen content of 10% will not sustain a fire. It is also possible that a reduction in oxygen concentration by several percent will slow the formation of the free radicals in the fire resulting in slower propagation. Figure 6 combines molecular weight and concentration resulting in weight per volume suppressed ( $1 \times 10^{-2}$  lb/ft<sup>3</sup>). Even though Helium requires a 40% concentration, the resultant agent weight is less than half that of Halon-1301. Similarly, water shows a slight advantage over Halon-1301 also. Nitrogen and carbon dioxide are among the best of the other agents plotted. Therefore, OAC nonazide propellant combustion byproducts ( $H_2O$ ,  $CO_2$ ,  $N_2$ ) should be extremely effective fire suppression agents. Similarly, water and carbon dioxide should be ideal hybrid agents.

Table 1. Specific Heat Capacity (Cp), Molecular Weight (mw),  
Ozone Depletion Potential (ODP) for Various Gases/Agents

Gas/Agent	Cp @ +70°F (Btu/lbm °R)	Molecular Weight	ODP	Notes
He	1.251	4	0	Inert gas
H <sub>2</sub> O	0.510	18	0	Vapor
N <sub>2</sub>	0.250	28	0	
Ne	0.246	20	0	Inert gas
CO <sub>2</sub>	0.203	44	0	Vapor
CH <sub>2</sub> F <sub>2</sub>	0.198	52	0	Flammable (HFC-32)
C <sub>3</sub> F <sub>8</sub>	0.188	188	0	(FC-218)
C <sub>4</sub> F <sub>10</sub>	0.182	238	0	(FC-31-10)
CHF <sub>3</sub>	0.175	70	0	(HFC-23)
CH <sub>4</sub>	0.166	88	0	(FC-14)
C <sub>2</sub> HF <sub>3</sub> Cl <sub>2</sub>	0.163	153	0.02	(HCFC-123)
CHF <sub>2</sub> Cl	0.158	86	0.05	(HCFC-22)
Ar	0.127	40	0	Inert gas
CF <sub>3</sub> Br	0.112	149	10	(H-1301)
CF <sub>2</sub> ClBr	0.108	165	3	(H-1211)
CHF <sub>2</sub> Br	0.092	131	1.2	(H-1201)
CF <sub>3</sub> I	0.086	196	0.01	Toxic?

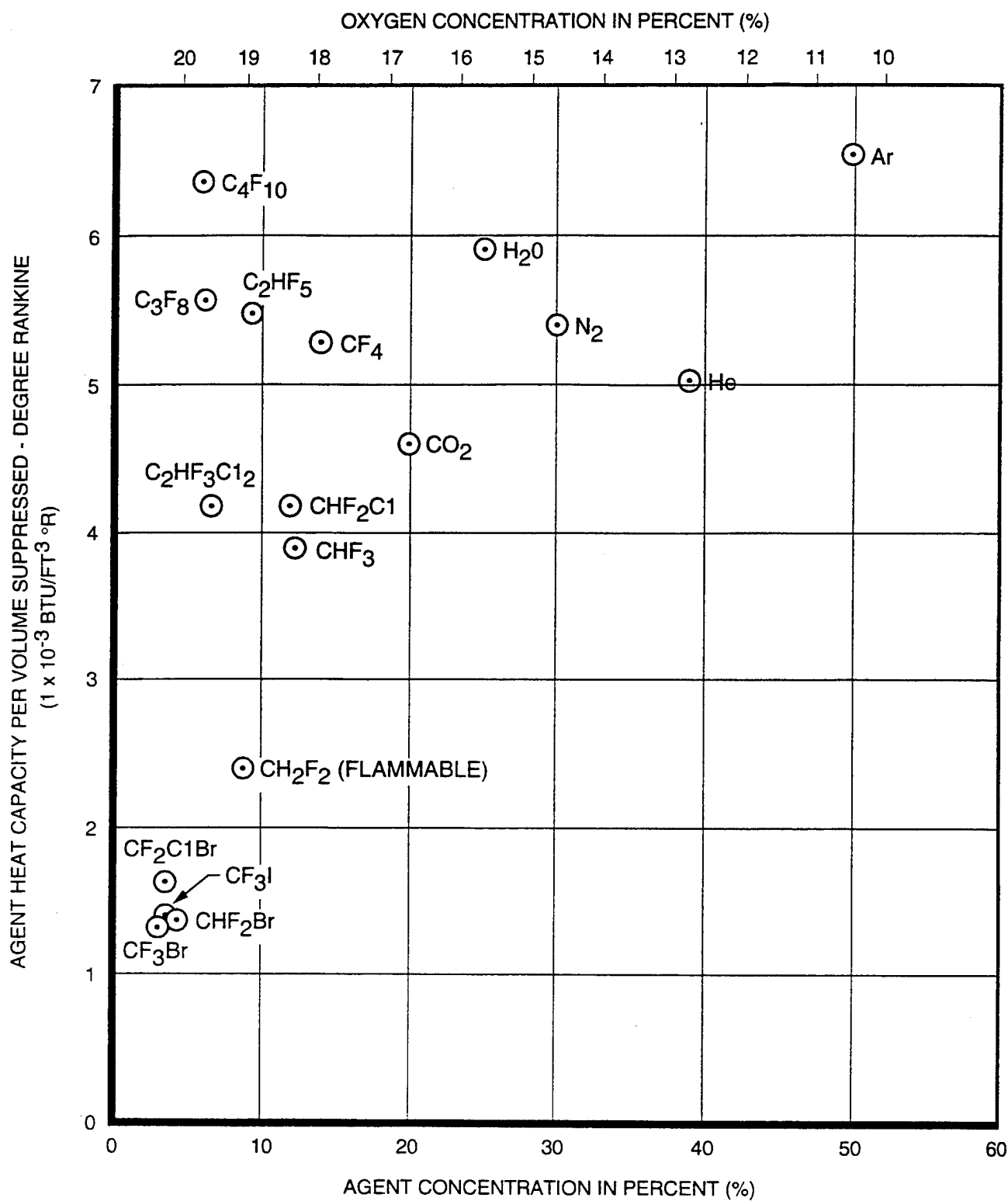


Figure 5  
Agent Heat Capacity Versus Concentration

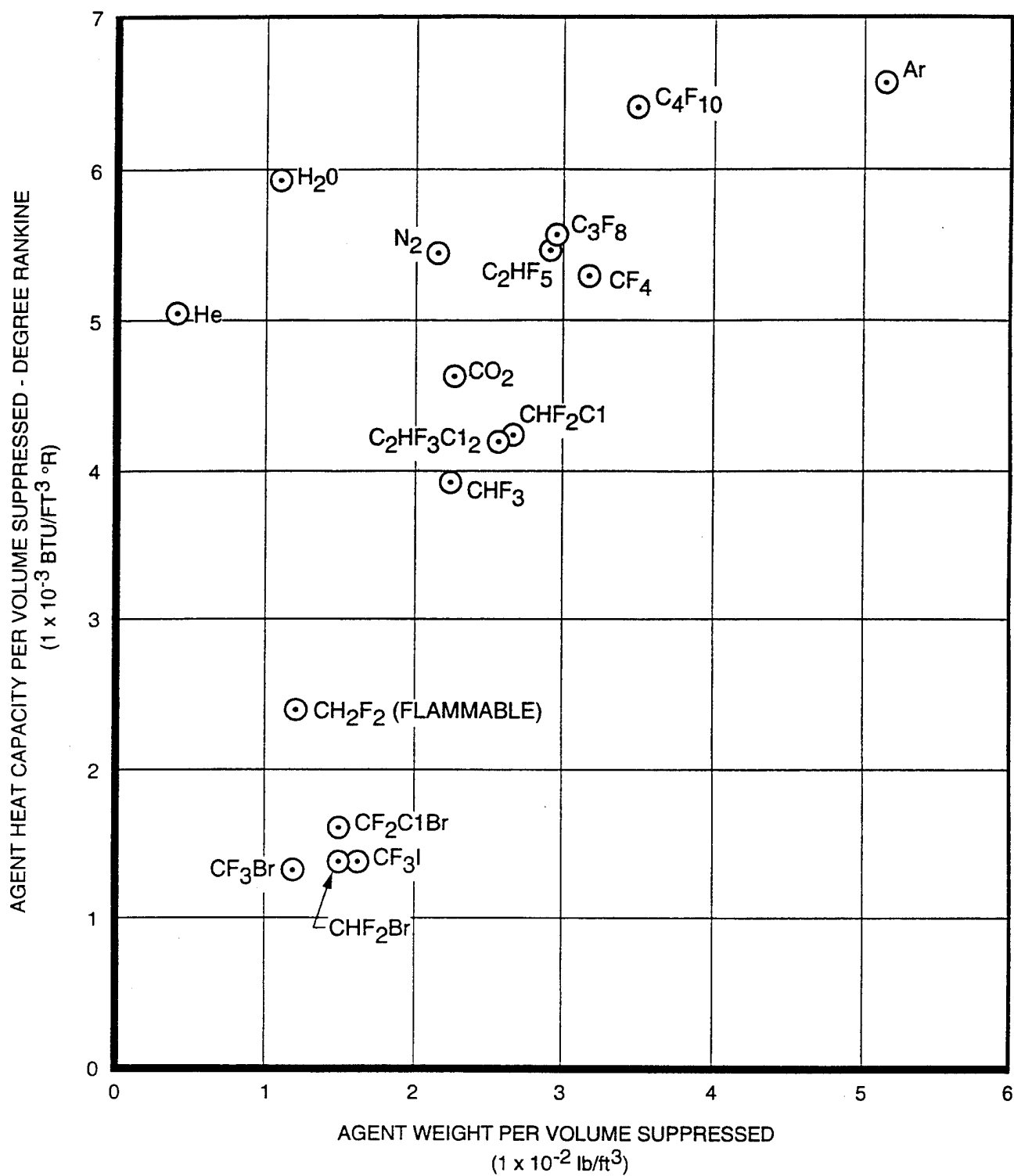


Figure 6  
Agent Heat Capacity Versus Weight

## SUMMARY

Phase I test activities focused on the initial evaluation of several gas generator configurations against two drybay and two engine nacelle fire scenarios (runs). Gas generator configurations included units with and without particulate filters and hybrid configurations in which the solid propellant gas generator pressurizes and discharges a secondary agent. Propellant and propellant / hybrid loads were adjusted to determine the minimum agent weight required for suppression of the fires.

Drybay testing in Run No. 28 configuration required .12 lbm of Halon-1301 to extinguish the fire. Four tests of a filtered radial flow gas generator resulted in a final agent weight of .154 lbm or 128% of the required Halon weight. Three tests of a nonfiltered generator resulted in a final weight estimate of .220 lbm. A filtered CO<sub>2</sub> hybrid unit required .183 lbm after three tests with a CO<sub>2</sub> to propellant weight ratio of 63%.

Testing in the second drybay configuration, labeled Run No. 31, required slightly higher amounts of Halon and significantly higher amounts of propellant for the nonhybrid solid units. The Filtered CO<sub>2</sub> hybrid performed better compared to the solid systems with a final agent weight of .261 lbm or 131% of the required Halon weight. The filtered and nonfiltered generators resulted in final weights of .617 and .551 lbm respectively. Three shots of each generator configuration were performed. One additional test was conducted using FM-200 as the hybrid agent at the same load as the last CO<sub>2</sub> hybrid test. Based on the visual results of the test, it was felt that the FM-200 was equivalent, if not superior to the CO<sub>2</sub>.

Drybay testing demonstrated that the solid and hybrid gas generator systems could perform well on an agent weight comparison to Halon 1301 in the scenarios tested. In addition, parameters such as discharge time and distribution characteristics, although not directly evaluated, were seen to be significant in the effectiveness of the systems and the most likely cause of the differences observed between the generator configurations.

Testing of the engine nacelle fire suppression started with a configuration labeled Run No. 30 which required .280 lbm of Halon. Seven gas generator configurations were tested with results as shown below:

### WPAFB ENGINE NACELLE TEST RESULTS SUMMARY

#### Run No. 30

AGENT	Test Qty	Estimated Final Agent Weight		GG/H-1301 Agent Weight Ratio	
		Bulk Fire Out	Thermocouple Re-Ignition	Bulk Fire Out	Thermocouple Re-Ignition
H-1301	4	.280	.280	N/A	N/A
Filtered GG	3	.275	.385	.98	1.38
Nonfiltered GG	3	> .330	.385	> 1.18	1.38
Nonfltrd 33% H <sub>2</sub> O Hybrid	3	.500	> .991	1.79	> 3.54
Fltrd 74% FM-200 Hybrid	3	.489	.698	1.75	2.49
Fltrd 70% PFC-614 Hybrid	2	> .771	---	> 2.75	---
Nonfltrd 20% H <sub>2</sub> O Hybrid	2	.798	---	2.85	---
Nonfltrd 20% COLD FIRE Hybrid	1	> .551	---	> 1.97	---

Olin Aerospace Company experienced an unusual phenomenon not previously encountered by WPAFB personnel during Run No. 30 testing. Several seconds after extinguishing the bulk fire, the braid covering thermocouple leads ignited and burned like a candle. No other surfaces ignited although hydraulic fluid was dripping off of many surfaces. Data was recorded for both agent weight to achieve bulk fire out and no re-ignition of the thermocouple leads. All tests in Run No. 30 were conducted with the gas generator located in the top distribution port. The fire was also located in the top of the annular nacelle volume.

As shown above, the filtered and nonfiltered solid propellant systems performed very well although a higher propellant load was required to prevent re-lights of the thermocouple braid. Even with the extra propellant to prevent re-ignition, the propellant to Halon weight ratio was 1.38:1. All of the hybrid configurations required more agent.

Following Run No. 30 testing, performance was evaluated against Nacelle Run No. 28 which required 1.125 lbm of halon to extinguish the fire utilizing JP-8 fuel as opposed to hydraulic fluid used in Run No. 30. The fire was also located on the bottom rather than the top of the nacelle volume. Three tests were conducted with a nonfiltered generator configuration in the top port yielding an estimated agent weight of 3.08 lbm or a propellant to Halon ratio of 2.74. Additional testing using the top port and a side and bottom port dropped the required agent weight to 2.20 lbm, a reduction of 28%.

Engine nacelle testing provided further verification that proper distribution is an important parameter of the gas generator fire suppression systems. Time did not permit sufficient testing to determine optimum agent weight. Future testing will provide further optimization while evaluating improved distribution and reduced discharge times.



## INTRODUCTION

The Advanced Fire Suppression Technology (AFST) Research and Development Program is being conducted by OAC for Wright Patterson Air Force Base (WPAFB) under Contract No. F33615-93-C-3404. The three phase program goal is to evaluate the effectiveness of gas generator technology to replace Halon in suppressing aircraft drybay and engine nacelle fires. This activity includes the design, development and testing of solid propellant and hybrid gas generator technology. Phase I, which is complete, includes an initial evaluation of filtered and nonfiltered solid propellant gas generators as well as select hybrid agents. As the Phase I interim report, this document provides a summary of the Phase I activities. Phase II provides opportunity to optimize the most promising Phase I systems. Phase III development will include propellant optimization.

In March and August 1994, OAC completed Phase I drybay and engine nacelle fire suppression testing, respectively. The scope of this activity included design, fabrication and development of filtered and nonfiltered solid propellant and hybrid gas generators. Actual fire suppression tests were conducted at WPAFB Wright Laboratory facilities including the Aircraft Survivability Research Facility (ASRF) and the Aircraft Engine Nacelle Test Facility (AENTF). The objective of this report is to document the Phase I activities performed and provide a recommended scope of work for the Phase II follow-on development program.

The following sections will present an overview of the design and development of the test articles used in the drybay and engine nacelle testing followed by individual sections detailing the drybay and engine nacelle testing results, conclusions and recommendations.

## TEST ARTICLE DESIGN and DEVELOPMENT

### PROPELLANT

The propellant that OAC chose to utilize for Phase I development is RRC-FS01-40 which is a proprietary mix developed for fire suppression. This propellant is a modified version of a nonazide automobile airbag propellant. The ingredients were modified to change the exhaust particulate constituents such that no material compatibility issues exist. Effluent compatibility studies indicate no reaction or pitting occurs with the following materials:

- 6061-T6 (Alodined)
- 7075-T6 (Mil-P-85582 coated)
- 7050 (Mil-P-85582 coated)
- Ti-6Al-4V (Bare)
- Graphite Epoxy
- Kevlar

In addition, the propellant has survived an accelerated aging test comprised of 244°F for 1000 hours and showed no performance degradation.

While the ingredients to RRC-FS01-40 propellant are proprietary, OAC must divulge the exhaust gas composition since the exhaust gas is the actual agent used in suppressing the fire. (Note: Although the exhaust gas is the actual fire extinguishing agent, this report will consider agent weight to be the weight of the propellant to simplify comparisons to the Halon system.) Table 2 provides detailed gas properties of the propellant. The propellant generates 54.25% gas products and 45.75% solid particulate. The gaseous products consist of 42.5% N<sub>2</sub>, 44.7% CO<sub>2</sub> and 12.8% H<sub>2</sub>O by weight. Approximately 95% of the solid particulate remain in the gas generator regardless of the gas generator configuration.

### GAS GENERATORS

All the gas generators constructed in Phase I development are of a heavyweight refurbishable design. That is, the devices are capable of hundreds of tests each and can survive HEI fragmentation impact should a HEI threat detonate in close proximity. This technique has been shown to be the most cost effective means to fabricate test hardware when weight is not an issue.

Prior to delivery at WPAFB, OAC must characterize each gas generator configuration to ensure it is functioning correctly. Gas generator characterization tests are performed in an evacuated 100 liter sealed tank. Upon functioning, OAC evaluates the following:

- Bulk average gas temperature
- Moles of gas produced
- Flow rate and time
- Particulate dust expelled

Characterization tests are described in-depth in the following sections.

Table 2. RRC FS01-40 Propellant Data Sheet

- Part No. RRC-FS01-40
- Size Various
- Burn Rate Proprietary
- Exponent (n) Proprietary
- Density Proprietary
- D.O.T. Classification 1.3 (Class B)
- Gas Properties (based on 100 g propellant)

	<b>Moles/ 100 g</b>	<b>Grams/ 100 g</b>	<b>Weight (%)</b>	<b>Volume (Mole) (%)</b>
N <sub>2</sub>	0.82356	23.06	42.5	46.8
CO <sub>2</sub>	0.55126	24.25	44.7	31.3
H <sub>2</sub> O	0.38572	6.94	12.8	21.9
<b>Total Gas</b>	<b>1.761</b>	<b>54.25</b>	<b>100</b>	<b>100</b>

- Solids Properties (based on 100 g propellant)

<b>Total Solids</b>	<b>45.75</b>	<b>100</b>
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### Drybay Test Articles

The four configurations OAC chose to develop for suppression testing at WPAFB are:

- Nonfiltered solid propellant gas generator
- Filtered solid propellant gas generator
- Filtered CO<sub>2</sub> hybrid gas generator
- Filtered FM-200 hybrid gas generator

Since the gas generators are all designed to fit within the drybay, they are designed to be radial flow and nonpropulsive. Therefore, OAC has coined the term Gas Generator Radial Flow Extinguisher (GGRFE).

The nonfiltered GGRFE is illustrated in Figure 7. There are four assemblies (-301 through -304) of various lengths and propellant loads. This allows OAC the ability to double or halve the propellant load during testing with relative ease. Table 3 tabulates the characterization tests performed on the nonfiltered GGRFE. The bulk average gas temperature was found to be 1000°F to 1200°F and approximately 2.6 grams of particulate dust is expelled per 100 grams of propellant load. The nonfiltered GGRFE function time was found to be 120 milliseconds as illustrated in Figure 8 which plots 100 liter tank pressure as a function of time.



Table 3 AFST Program Phase I Drybay  
Nonfiltered GGRFE Characterization Test Summary

ym155/9-19-94/T2-1

Test No. (F883-)	FS01-40 Propellant Load (Grams) ②	Total Moles Gas (Theo)	P <sub>TANK</sub> (Max) (kPa) ③	T <sub>GAS</sub> (Avg) (°F) ④	P <sub>TANK</sub> (Sat/Amb) (kPa) ⑤	T <sub>AMB</sub> (°C) ⑤	Sat./Am. Moles Gas (Actual/ Theo.) ⑤	Gas Gen. ΔW (Actual/ Theo.) (Grams) ⑥	Particulate Expelled (Actual/ Theo.) (Grams)
012	196.5	3.46	258	1155	69	23.5	2.80/2.82	121.1/106.6	6.3/14.5
014	143.2	2.52	190	1173	52	23.6	2.11/2.09	82.9/77.7	3.6/5.2
015	131.2	2.31	162	1060	47	23.6	1.92/1.92	75.4/71.2	2.5/4.2
016	104.2	1.83	125	1016	39	23.2	1.58/1.55	64.4/56.3	2.6/8.1

**Notes:**

- ① 25.68 grams FS01-40 per linear inch packing volume.
- ② 0.375 dia x .095 thick propellant, 110-130 msec nominal burn time.
- ③ 100 liter tank data ~ 120 msec.
- ④ After losses to tank ~ 120 msec.
- ⑤ At saturated/ambient conditions @ ~ 2 min.
- ⑥ Actual includes gas and particulate expelled, theoretical is gas only expelled.

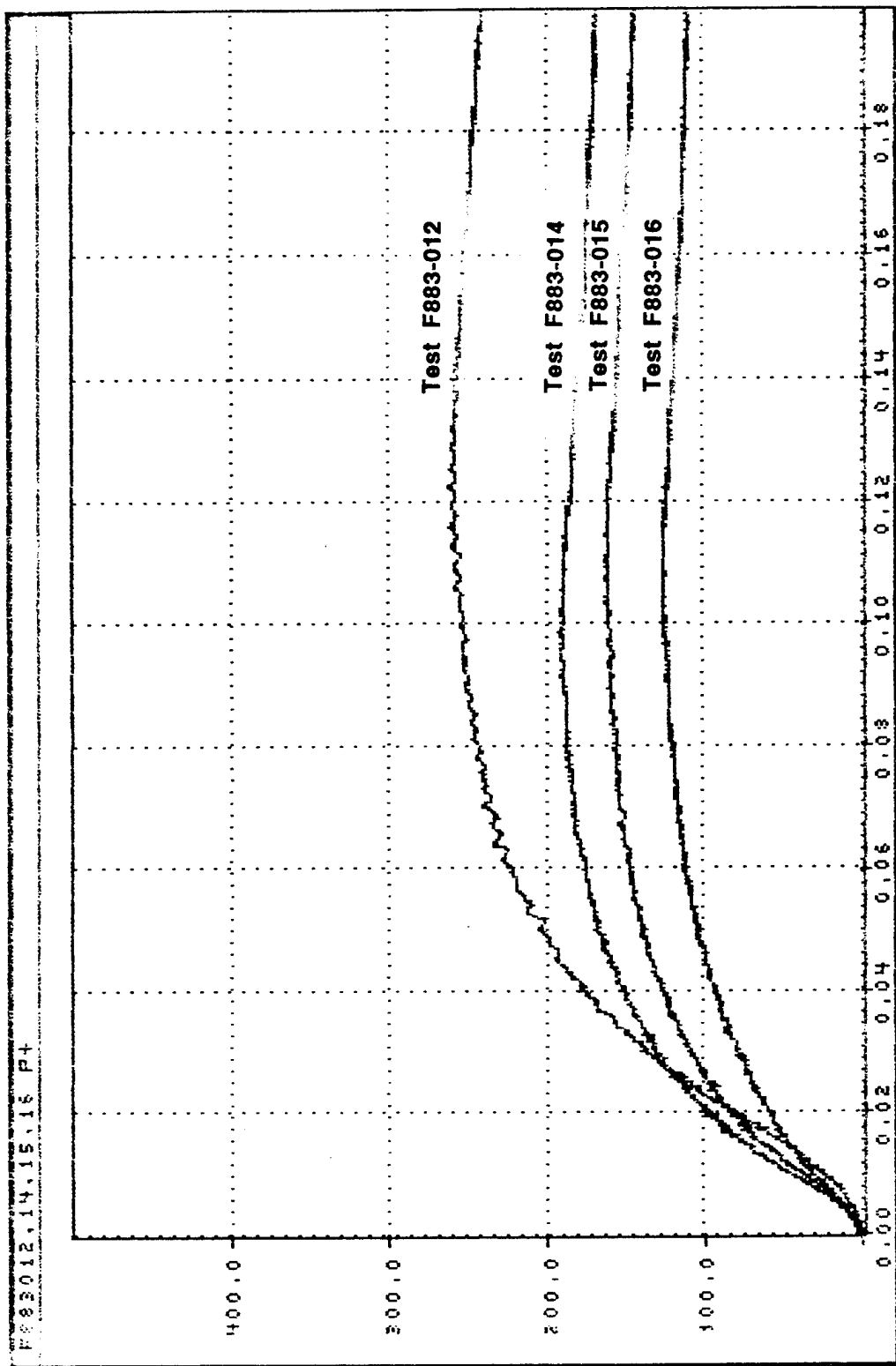


Figure 8  
Nonfiltered GGRFE 100 Liter Tank Pressure Versus Time

The filtered GGRFE is depicted in Figure 9. There are three assemblies (-301 through -303) of various lengths and propellant loads. Table 4 tabulates the characterization tests performed on the three assemblies. The bulk average gas temperature was found to be 800°F to 1000°F and approximately 1.1 grams of particulate dust is expelled per 100 grams of propellant load. The filtered GGRFE function time was found to be 90 milliseconds as illustrated in Figure 10.

The gas generator utilized to expel the hybrid agents is depicted in Figure 11. There are two assemblies of propellant loads. Table 5 documents the characterization test performed using carbon dioxide as the hybrid agent. As discussed earlier, hybrid gas generators will have significantly reduced gas temperatures. For the propellant/CO<sub>2</sub> load tested (71 grams/121 grams), the bulk average gas temperature was 121°F. Only 0.1 grams of particulate dust is expelled per 100 grams of total agent load.

### **Engine Nacelle Test Articles**

The four configurations OAC chose to develop for suppression testing at WPAFB Engine Nacelle facility are:

- Nonfiltered solid propellant gas generator
- Filtered solid propellant gas generator
- Nonfiltered hybrid gas generator (various agents)
- Filtered hybrid gas generator (various agents)

Since the engine nacelle is designed to accommodate suppressors mounted externally, all the gas generators are of an axial-flow design.

Figure 12 depicts the nonfiltered gas generator. There are three configurations (-301 through -303) of various lengths and propellant loads. Table 6 tabulates the test performed to ensure proper operation. The bulk average gas temperature was 1179°F which is in line with the drybay GGRFE. Approximately 1.8 grams of particulate dust is expelled per 100 grams of propellant. The nonfiltered gas generator function time was found to be 140 milliseconds as shown in Figure 13.

The filtered solid propellant gas generator is depicted in Figure 14. The hardware is identical to the nonfiltered configuration except a filter is installed around the propellant. There are three configurations (-301 through -303) of varying length and propellant load. Table 7 documents the characterization tests performed for the filtered gas generator. The bulk average gas temperature was found to be 500°F to 700°F. Approximately 1.0 grams of particulate is expelled per 100 grams of propellant load. The filtered gas generator function time was found to be 180 milliseconds as indicated in Figure 15.

The nonfiltered and filtered hybrid units for engine nacelle testing utilized the nacelle gas generators illustrated in Figures 12 and 14 with the addition of a hybrid tank connected to the output to contain the hybrid agent. Characterization tests were not performed on the nacelle hybrid units.





Table 4 AFST Program Phase I Drybay  
Filtered GGRFE Characterization Test Summary

ym155/9-19-94/T2-2

Test No. (96033-)	Propellant Load (Grams) ②	Total Moles Gas (Theo)	P <sub>TANK</sub> (Max) (kPa) ③	T <sub>GAS</sub> (Avg) (°F) ④	P <sub>TANK</sub> (Sat/Amb) (kPa) ⑤	T <sub>AMB</sub> (°C) ⑤	Sat./Am. Moles Gas (Actual/Theo) ⑤	Gas Gen. ΔW (Actual/Theo) (Grams) ⑥	Particulate Expelled (Actual/ Theo) (Grams)
05	247	4.34	286	966	87	23.5	3.53/3.51	135.7/133.4	2.4/2.3
06	163	2.86	188	964	60	23.0	2.44/2.36	90.1/88.0	2.0/2.1
07	81	1.43	88	873	32	21.7	1.29/1.22	45.1/43.7	0.9/1.4

**Notes:**

- ① 25.7 grams FS01-40 per linear inch packing volume.
- ② 0.375 dia x .095 thick propellant, 80-100 msec nominal burn time.
- ③ 100 liter tank data ~ 90 msec.
- ④ After losses to tank ~ 90 msec.
- ⑤ At saturated/ambient conditions @ ~ 2 min.
- ⑥ Actual includes gas and particulate expelled, theoretical is gas only expelled.

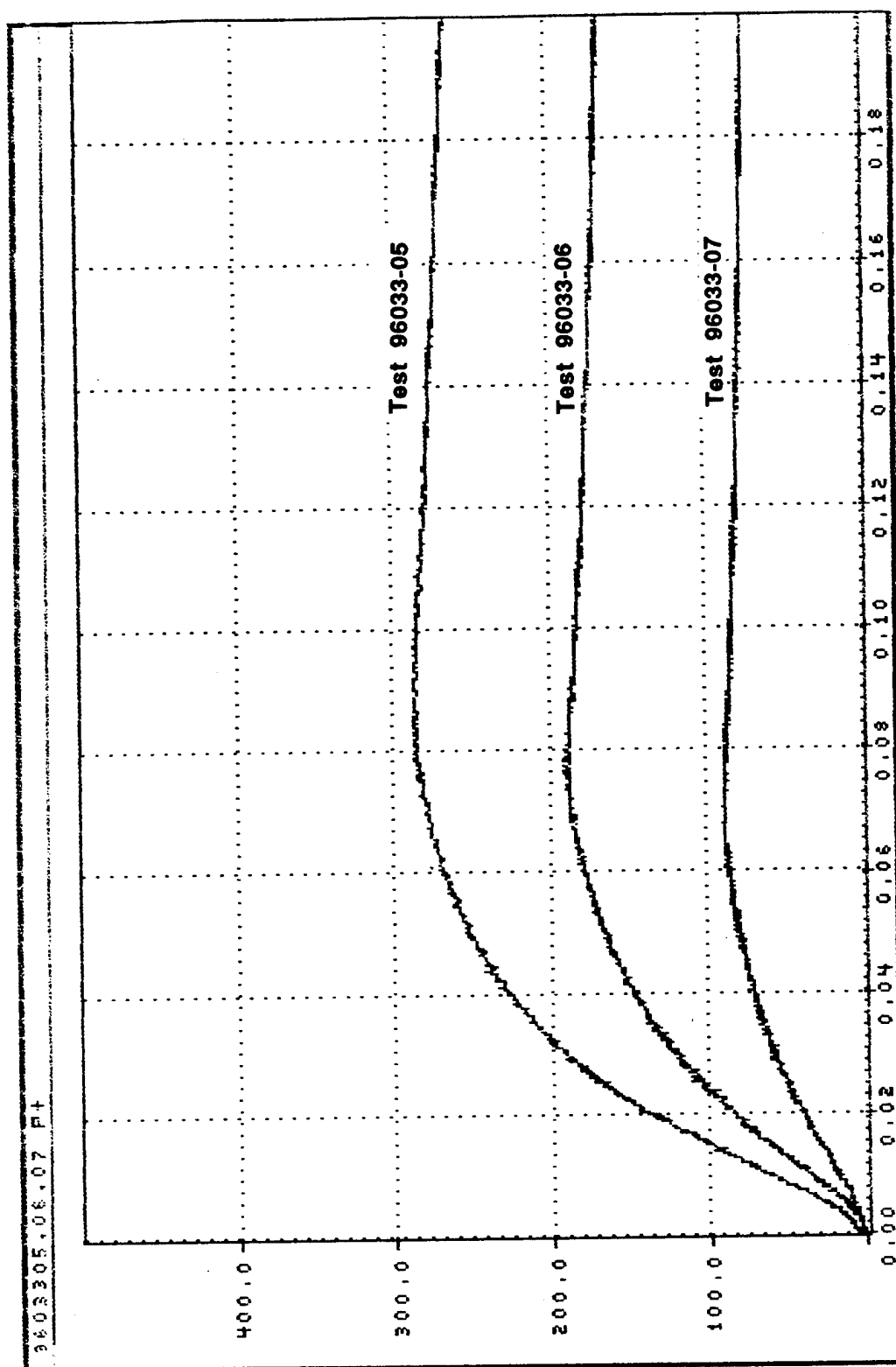


Figure 10  
Filtered GGRFE 100 Liter Tank Pressure Versus Time

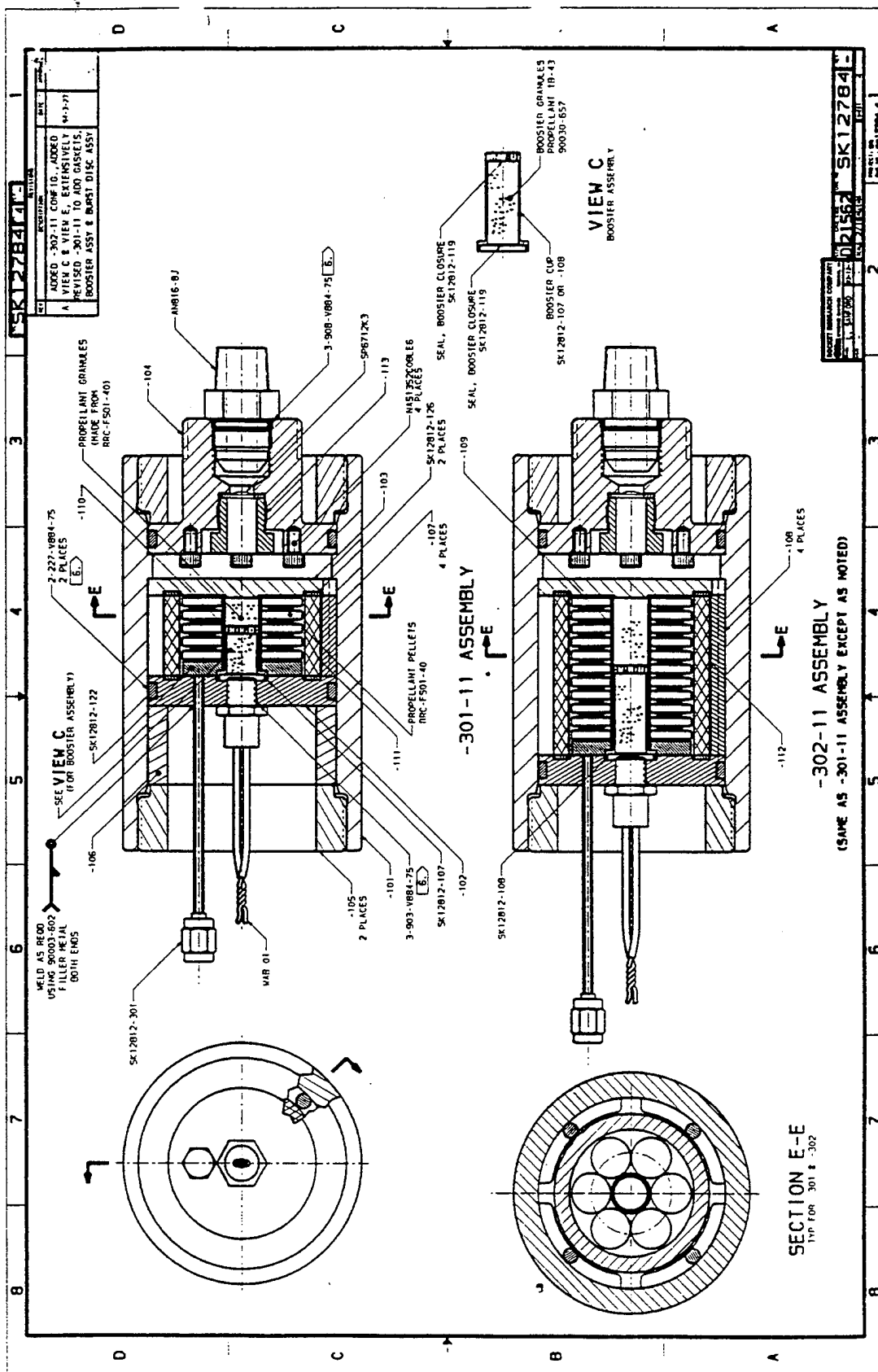


Figure 11  
SK12784 -- -302-11 -- Dry Hybrid Gas Generator

Table 5 AFST Program Phase I Drybay  
Filtered CO<sub>2</sub> Hybrid GG Characterization Test Summary

ym155/9-19-94/T2-3

Test No. (96046-)	Propellant/ CO <sub>2</sub> Load (Grams) ②	Total Moles Gas (Theo)	P <sub>TANK</sub> (Max) (kPa) ③	T <sub>GAS</sub> (Avg) (°F) ④	P <sub>TANK</sub> (Sat/Amb) (kPa) ⑤	T <sub>AMB</sub> (°C) ⑤	Sat./Am. Moles Gas (Actual/ Theo) ⑤	Gas Gen. ΔW (Actual/Theo) (Grams) ⑥	Particulate Expelled (Actual/ Theo) (Grams)
-05	71/121	3.99	107	121	91	22.2	3.71/3.83	159.5/158.8	0.2/0.7

**Notes:**

- ① 25.68 grams FS01-40 per linear inch packing volume.
- ② 0.375 dia x .095 thick propellant, 100–120 msec nominal burn time.
- ③ 100 liter tank data ~ 160 msec.
- ④ After losses to tank ~ 160 msec.
- ⑤ At saturated/ambient conditions @ ~ 2 min.
- ⑥ Actual includes gas and particulate expelled, theoretical is gas only expelled.

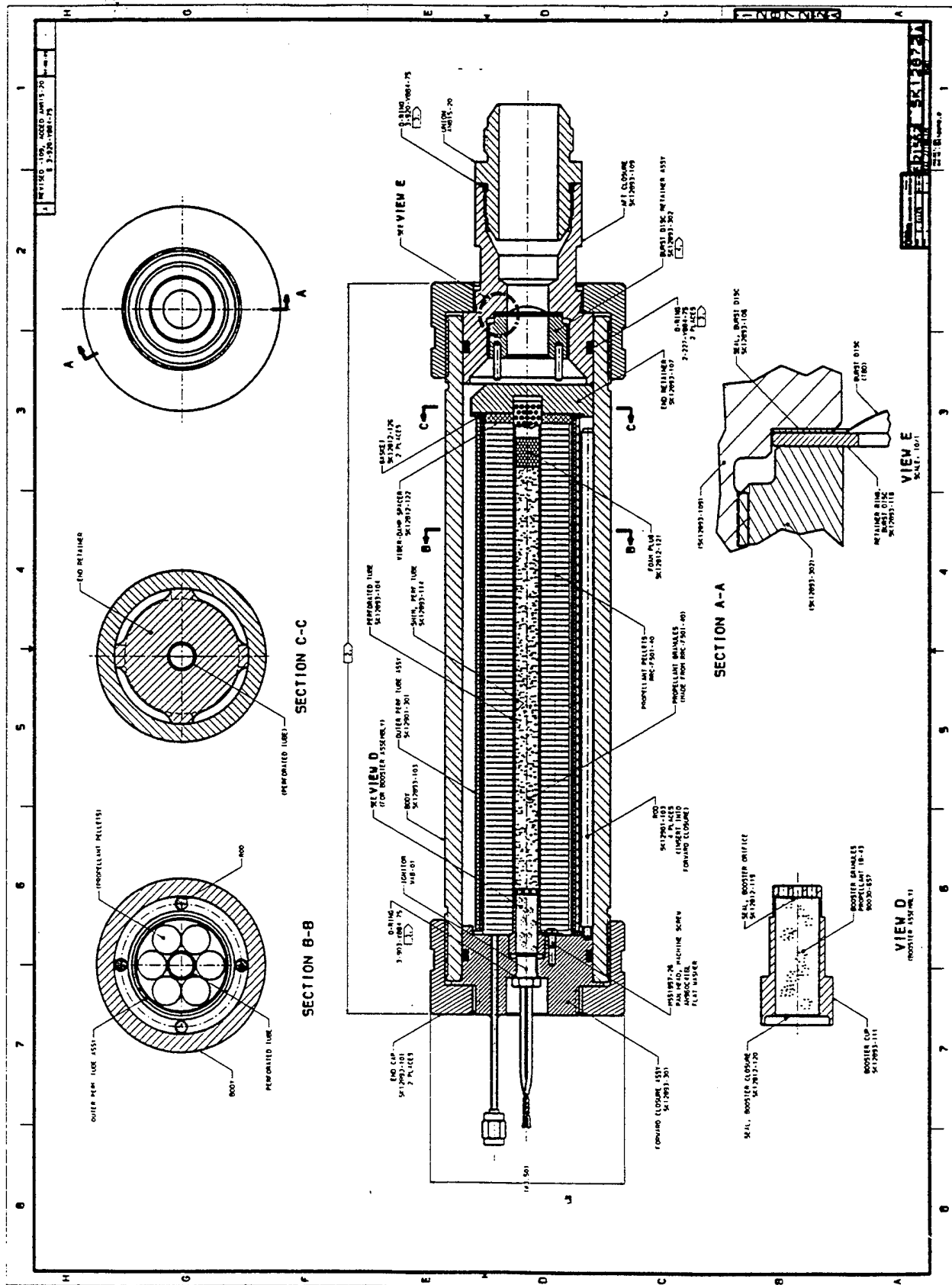


Figure 12  
SK12872 - Nonfiltered, Axial Flow Gas Generator

Table 6 AFST Program Phase I Engine Nacelle  
Nonfiltered Axial Flow GG Characterization Test Summary

vm155/9-19-94/T2-4

Test No. (96076-)	Propellant Load (Grams) ②	Total Moles Gas (Theo)	P <sub>TANK</sub> (Max) (kPa) ③	T <sub>GAS</sub> (Avg) (°F) ④	P <sub>TANK</sub> (Sat/Amb) (kPa) ⑤	T <sub>AMB</sub> (°C) ⑤	Sat./Am. Moles Gas (Actual/ Theo) ⑤	Gas Gen. ΔW (Actual/Theo) (Grams) ⑥	Particulate Expelled (Actual/ Theo) (Grams)
11	429	7.56	572	1179	152	33	6.03/6.10	266.8/231.7	7.9/35

**Notes:**

- ① 45.0 grams FS01-40 per linear inch packing volume.
- ② 0.50 dia x .250 thick propellant, 150-170 msec nominal burn time.
- ③ 100 liter tank data ~ 160 msec.
- ④ After losses to tank ~ 160 msec.
- ⑤ At saturated/ambient conditions @ ~ 2 min.
- ⑥ Actual includes gas and particulate expelled, theoretical is gas only expelled.

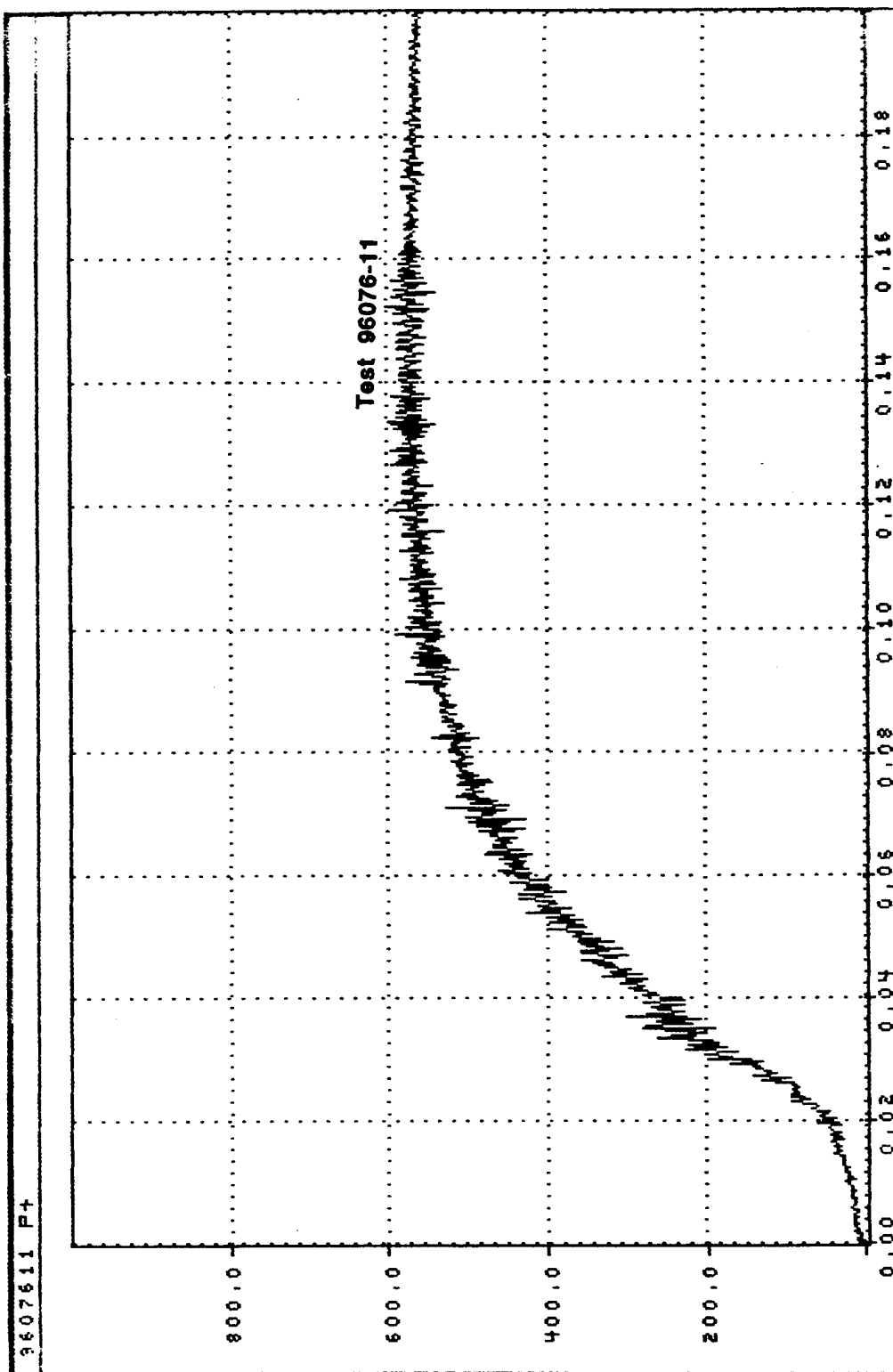


Figure 13  
Nonfiltered Gas Generator 100 Liter Tank Pressure Versus Time





Table 7 AFST Program Phase I Engine Nacelle  
Filtered Axial Flow GG Characterization Test Summary

ym155/9-19-94/T-2-5

Test No. (96076-)	Propellant Load (Grams) ②	Total Moles Gas (Theo)	P <sub>TANK</sub> (Max) (kPa) ③	T <sub>GAS</sub> (AVg) (°F) ④	P <sub>TANK</sub> (Sat/Amb) (kPa) ⑤	T <sub>AMB</sub> (°C) ⑤	Sat./Am. Moles Gas (Actual/ Theo.) ⑤	Gas Gen. ΔW (Actual/Theo) (Grams) ⑥	Particulate Expelled (Actual/ Theo.) (Grams)
07	431	7.59	384	636	154	28	6.15/6.08	242.3/232.7	NA/9.6
09	217	3.81	171	512	76	25.5	3.06/3.12	120.2/117.2	1.9/3.0
12	107	1.89	88	549	40	25.0	1.61/1.60	60.7/57.8	1.4/2.9

**Notes:**

- ① 45.0 grams FS01-40 per linear inch packing volume.
- ② 0.500 dia x .250 thick propellant, 160–200 msec nominal burn time.
- ③ 100 liter tank data ~ 180 msec.
- ④ After losses to tank ~ 180 msec.
- ⑤ At saturated/ambient conditions @ ~ 2 min.
- ⑥ Actual includes gas and particulate expelled, theoretical is gas only expelled.

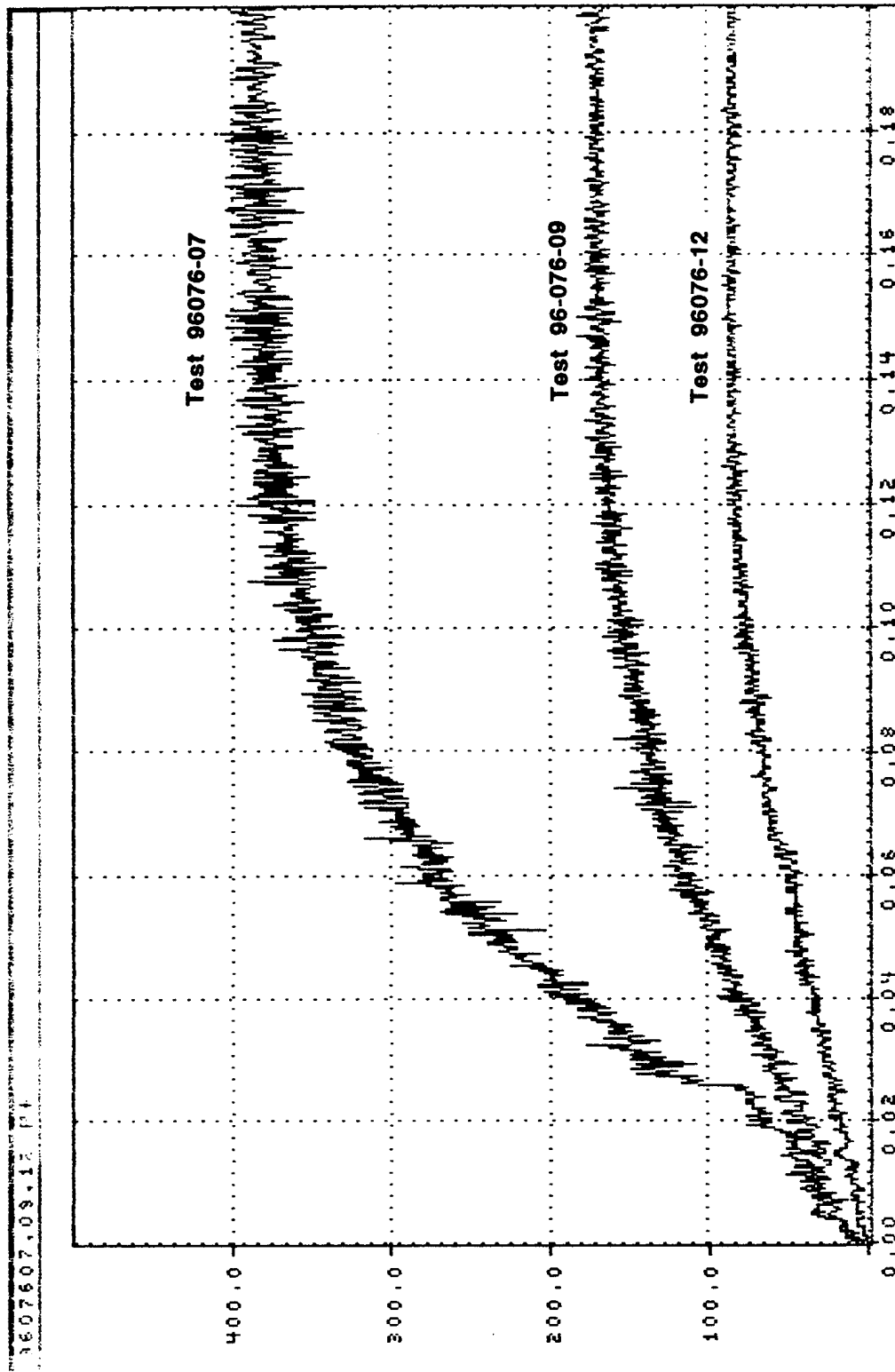


Figure 15  
Filtered Gas Generator 100 Liter Tank Pressure Versus Time

## **DRYBAY TEST RESULTS / CONCLUSIONS / RECOMMENDATIONS**

In March 1994, OAC completed Phase I drybay fire suppression testing at WPAFB Wright Laboratory Aircraft Survivability Research facility. A total of two drybay simulators were tested, each with different parameters. Both drybay fixtures were shot at with HEI threats and had 400 knots external airflow. The fixtures were characterized with Halon-1301, prior to OAC arrival.

### **RUN NO. 28 RESULTS**

Figure 16 depicts the 11 ft<sup>3</sup> drybay for WPAFB run no. 28. The drybay has a 4:1 length to height ratio and 500 cfm internal airflow. Clutter simulation was cleverly provided by perforated plates with 33% open area. One gas generator was used at the Halon-1301 bottle discharge location. JP-8 fuel preheated to 100°F was used.

Table 8 documents the Halon-1301 and gas generator test results. Three gas generator configurations were tested as follows:

- Filtered GGRFE
- Nonfiltered GGRFE
- Filtered Hybrid CO<sub>2</sub> (63% CO<sub>2</sub>)

A total of four filtered GGRFE's were tested which resulted in a final weight of 0.154 lbm which is only 1.28 times the Halon-1301 weight. The nonfiltered GGRFE was tested three times with a final weight of 0.220 lbm or 1.83 times the halon weight. Lastly, a filtered CO<sub>2</sub> hybrid gas generator was tested three times resulting in a final weight of 0.183 lbm which is 1.53 times the Halon-1301 final value.

Since the test time available was limited, not all gas generators could be tested with four iterations. If they could, the final weights could be 10% lower (or higher) depending on the outcome. Table 9 summarizes the important parameters of the three systems tested. The parameters include agent weight, bulk average gas temperature, moles of gas produced, particulate expelled and expulsion time.

### **RUN NO. 31 RESULTS**

Figure 17 depicts the 11 ft<sup>3</sup> drybay for WPAFB run no. 31. The drybay has a 1:1 length to height aspect ratio and 1000 CFM internal airflow. Clutter simulation utilized perforated plates with 66% open area. Two gas generators were used at the two Halon-1301 discharge locations. The gas generators were supported vertically resulting in the gas orifice exit plane being parallel to the length of the drybay. JP-8 fuel preheated to 150°F was used.

Table 10 documents the Halon-1301 and gas generator test results. Four gas generator configurations were tested for comparison to Halon-1301:

- Filtered GGRFE
- Nonfiltered GGRFE
- Filtered Hybrid - CO<sub>2</sub> (63% CO<sub>2</sub>)
- Filtered Hybrid - FM-200 (63% FM-200)

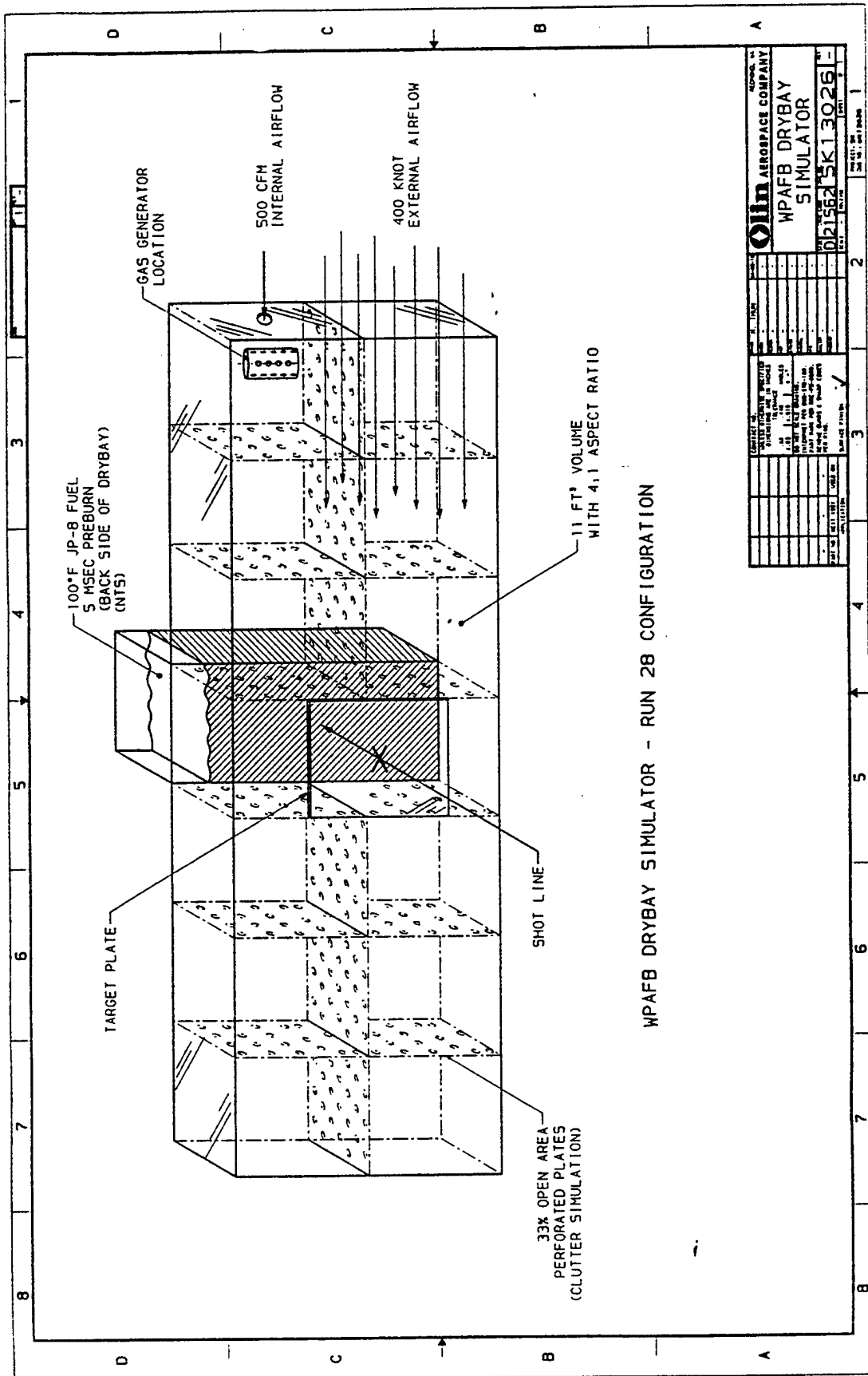


Figure 16  
SK13026 - WPAFB Drybay Simulator

Table 8 Phase I Drybay Fire Suppression  
WPAFB Run No. 28 ①  
Gas Generator Test Results

ym155/9-19-94/T3-1

Agent Tested	Agent Weight Tested (lbm)②				Final Agent Weight (lbm)	G.G./1301 Agent Wt. Ratio
	x = 1	x = 2	x = 3	x = 4		
H-1301	0.125	0.06	0.09	0.11	0.12	NA
Filtered GGRFE	0.352	0.176	0.088	0.132	0.154	1.28
Non-filtered GGRFE	0.176	0.352	0.264	—	0.220	1.83
Filtered Hybrid-CO <sub>2</sub> G.G.	0.209	0.105	0.157	—	0.183	1.53

Notes:

①

Run No. 28 Configuration

- 11 ft<sup>3</sup> drybay volume
- 400 knot external airflow
- 500 CFM internal airflow
- 4:1 drybay L/H aspect ratio
- 100°F JP-8 fuel w/5 msec preburn
- One suppressor upstream

②

XXX	- fire not extinguished
XXX	- fire extinguished

Table 9 Gas Generator Performance Criteria  
Phase I Drybay  
WPAFB Run No. 28 ①

ym155/9-16-94/T3-2

Gas Generator Configuration	Agent Weight (Lbs)			Bulk Average Gas Temperature (°F)	Moles of Gas Produced			Particulate Expelled (Grams)	Expulsion Time (Msec)
	Propellant	Other	Total		Propellant ②	Other	Total		
Filtered GGRFE	0.154	—	0.154	800–1000	1.23	—	1.23	0.7	90
Non-Filtered GGRFE	0.220	—	0.220	1000–1200	1.76	—	1.76	2.6	120
Filtered CO <sub>2</sub> – Hybrid GG	0.067	0.116 (CO <sub>2</sub> )	0.183	100–200	0.54	1.19 (CO <sub>2</sub> )	1.73	< 0.1	160

**Notes:**

- ① 0.12 Lb Halon — 1301 equivalency
- ② OAC Proprietary composition consisting of 46.8% N<sub>2</sub>, 31.3% CO<sub>2</sub>, 21.9% H<sub>2</sub>O vapor

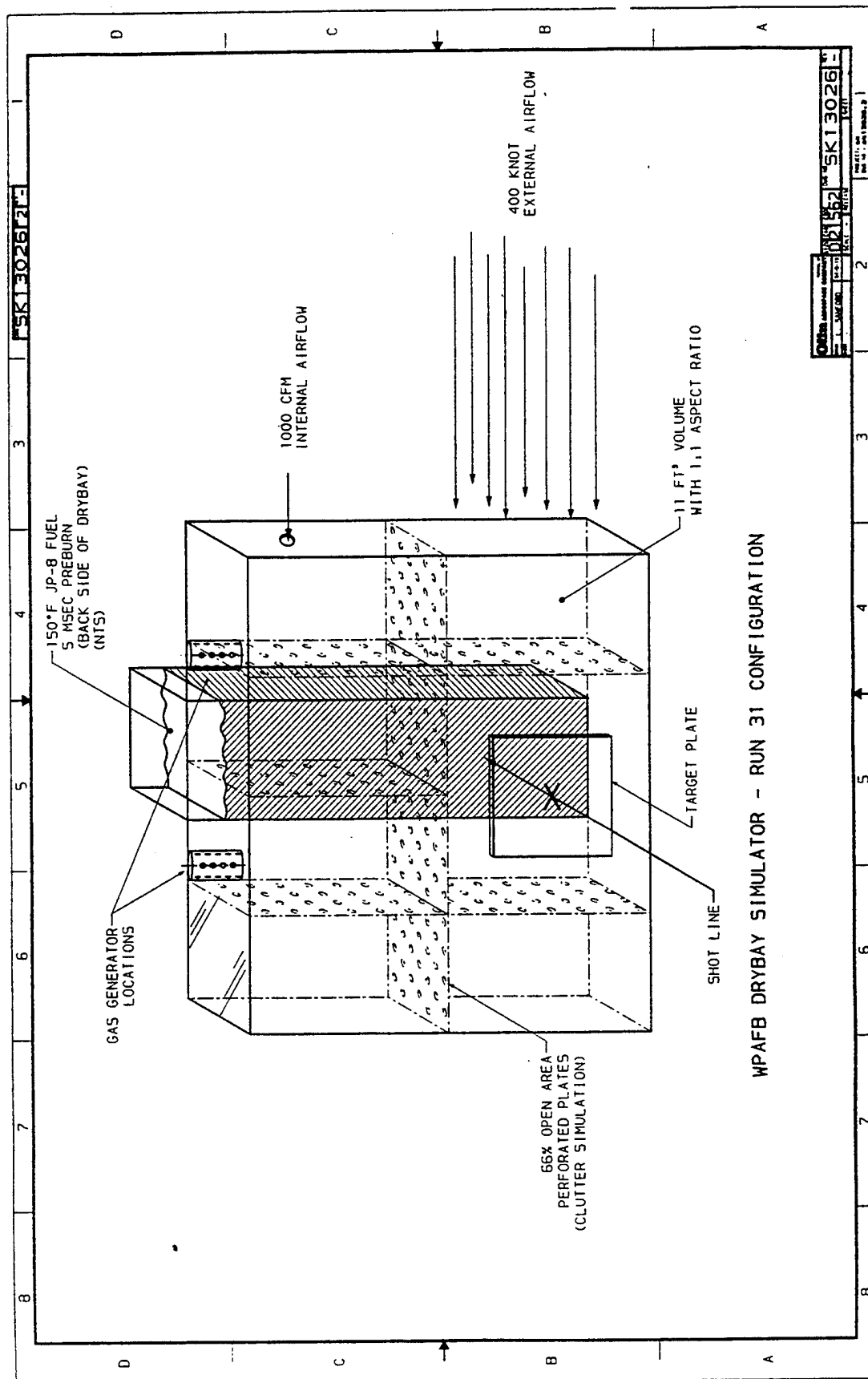


Figure 17  
SK13026 - WPAFB Drybay Simulator - Run 31 Configuration

Table 10 Phase I Drybay Fire Suppression  
WPAFB Run No. 31 ①  
Gas Generator Test Results

ym155/9-19-94/T3-3

Agent Tested	Agent Weight Tested (lbm)②				Final Agent Weight (lbm)	G.G./1301 Agent Wt. Ratio
	x = 1	x = 2	x = 3	x = 4		
H-1301	0.25	0.125	0.188	0.219	0.20	NA
Filtered GGRFE	0.352	0.705	0.529	—	0.617	3.09
Non-filtered GGRFE	0.441	0.881	0.661	—	0.551	2.76
Filtered Hybrid-CO <sub>2</sub> G.G.	0.419	0.209	0.313	—	0.261	1.31
Filtered Hybrid FM-200 G.G.	0.313	—	—	—	0.261③	1.31

Notes:

①

Run No. 31 Configuration

- 11 ft<sup>3</sup> drybay volume
- 400 knot external airflow
- 1000 CFM internal airflow
- 1:1 drybay L/H aspect ratio
- 150°F JP-8 fuel w/5 msec preburn
- One suppressor upstream and one suppressor downstream

②

XXX - fire not extinguished  
XXX - fire extinguished

③

1 test performed, considered equivalent to CO<sub>2</sub> hybrid



Three filtered GGRFE's were tested with a final weight of 0.617 lbm which is 3.09 times the halon weight. Three nonfiltered GGRFE's were also tested with similar results. The final value of the nonfiltered GGRFE was 0.551 lbm or 2.76 times the Halon-1301 weight. The filtered CO<sub>2</sub> hybrid gas generator performed much better. The final weight was 0.261 lbm which is 1.31 times the Halon-1301 weight. One test was conducted with the filtered hybrid using FM-200. The fire was extinguished using an agent weight of .313 lbm.

Since no configurations were tested four times, the final values are not optimized. The actual final values could be 10% lower or higher depending on the fourth test outcome.

Table 11 presents the important parameters of the four systems tested. The parameters include agent final weight, bulk average gas temperature, moles of gas produced, particulate expelled and expulsion time.

### **PRODUCTION WEIGHT/VOLUME**

Table 12 summarizes the production weights and volume for all gas generators tested in WPAFB run no. 28 and 31. For run no. 28, the filtered and nonfiltered GGRFE's are nearly identical in system weight and volume because the addition of the filter negates the advantage of a reduced agent weight. The filtered CO<sub>2</sub> hybrid gas generator weight is close to the filtered and nonfiltered GGRFE's. However, the volume required for the carbon dioxide is excessive resulting in twice the volume requirements.

For run no. 31, the nonfiltered GGRFE is advantageous over the filtered GGRFE. Although the filtered CO<sub>2</sub> hybrid agent weight was significantly lower than the filtered and nonfiltered GGRFE's, the extra volume required makes the system weight and volume similar. The filtered FM-200 hybrid agent volume is more efficient resulting in a very competitive package compared to Halon-1301.

### **CONCLUSIONS**

In WPAFB run no. 28, all gas generators performed well on an agent weight basis. The performance advantage of the filtered GGRFE over the nonfiltered GGRFE is likely due to the decreased expulsion time which was 90 msec for the filtered GGRFE and 120 msec for the nonfiltered GGRFE. Theoretically, the higher gas temperature of the nonfiltered GGRFE should make it superior if all other parameters are identical. The filtered CO<sub>2</sub> hybrid performed well although the longer expulsion time of 160 msec probably affected it. One test advantage that the filtered CO<sub>2</sub> hybrid had was a longer length which placed the exit orifices more in line with the fire.

In WPAFB run no. 31, the filtered and nonfiltered GGRFE's performed much worse than the previous run. However, the filtered CO<sub>2</sub> and FM-200 hybrid gas generators performed well compared to the GGRFE's and Halon-1301. After evaluating the differences between the two drybays, OAC believes that the filtered and nonfiltered GGRFE's were not oriented in the appropriate plane to allow the gaseous agent to reach the fire efficiently. The increased length of the hybrid gas generator combined with the orifice located on the end allowed the hybrid gas generators to reach the fire easier. Furthermore, OAC believes that the Halon-1301 discharge was vertical which would allow better distribution into the fire. The GGRFE's and hybrid gas generators all discharged horizontally. Additional evidence to support the orientation theory is the agent discharge time. In run no. 28, the faster discharge time clearly requires less agent. In run no. 31, this is not the case. Both GGRFE's performed similarly which would support the orientation issue.

Table 11 Gas Generator Performance Criteria  
Phase I Drybay  
WPAFB Run No. 31 ①

ym155/9-16-94/T3-4

Gas Generator Configuration	Agent Weight (Lbs)		Bulk Average Gas Temperature (°F)	Moles of Gas Produced			Particulate Expelled (Grams)	Expulsion Time (Msec)
	Propellant	Other		Propellant ②	Other	Total		
Filtered GGRFE	0.617	—	800–1000	4.93	—	4.93	3.0	90
Non-Filtered GGRFE	0.551	—	1000–1200	4.40	0	4.40	6.6	120
Filtered CO <sub>2</sub> – Hybrid GG	0.096	0.165	100–200	0.76	1.70	2.46	< 0.1	160
Filtered FM-200 Hybrid GG	0.096	0.165	100–200	0.76	0.44	1.20	< 0.1	160

**Notes:**

- ① 0.20 Lb Halon — 1301 equivalency
- ② OAC Proprietary composition consisting of 46.8% N<sub>2</sub>, 31.3% CO<sub>2</sub>, 21.9% H<sub>2</sub>O vapor
- ③ 1 test performed, considered equivalent/superior to CO<sub>2</sub> hybrid

Table 12 Phase I Drybay Fire Suppression  
Gas Generator Production Weight and Volume for WPAFB Test Configuration No. 28 and 31

ym155/9-16-94/T3-5

Halon-1301 <sup>①</sup>				Gas Generator						
WPAFB Run No. Configuration	Agent Weight (lbs) <sup>②</sup>	System Weight (lbs)	System Volume (in <sup>3</sup> )	Configuration	Agent Weight (lbs)	System Weight (lbs)	System Volume (in <sup>3</sup> )	Weight Ratio GG/1301		System Volume Ratio GG/1301
28 <sup>③</sup>	0.12	0.634	8.36	Filtered GGRFE	0.154	0.85	10.3	Agent	System	1.23
				Non-filtered GGRFE	0.220	0.83	10.3	1.83	1.31	
				Filtered CO <sub>2</sub> Hybrid GG	0.183	0.88	22.9	1.53	1.39	
31 <sup>④</sup>	0.20	0.789	10.6	Filtered GGRFE	0.617	2.60	33.0	3.09	3.30	3.11
				Non-filtered GGRFE	0.551	1.92	24.0	2.76	2.43	2.26
				Filtered CO <sub>2</sub> Hybrid GG	0.261	1.60	26.5	1.31	2.03	2.50
				Filtered FM-200 Hybrid GG	0.261 <sup>⑤</sup>	1.10	13.4	1.31	1.40	1.26

**Notes:**

- ① Data provided by WPAFB
- ② Does not include N<sub>2</sub> pressurant.
- ③ One suppressor used.
- ④ Two suppressors used - weight/volume is total.
- ⑤ One test performed - FM-200 considered equivalent/superior to CO<sub>2</sub>

## **RECOMMENDATIONS**

In Phase II, OAC will return to the Wright Laboratory Aircraft Survivability Research facility to improve the gas generator performance.

Olin Aerospace Company believes the following changes should be made to the gas generators.

- Decrease expulsion time to  $\approx 50$  msec.
- Delete the CO<sub>2</sub> hybrid due to CO<sub>2</sub> packing efficiency
- Complete filtered FM-200 hybrid testing in both run configurations
- Review Halon-1301 discharge orientation and modify gas generator discharge orientation

Olin Aerospace Company believes that if the above noted changes are made, the system weight and volume should be competitive with Halon-1301.

## ENGINE NACELLE TEST RESULTS / CONCLUSIONS / RECOMMENDATIONS

In August 1994, OAC performed Engine Nacelle Suppression tests using OAC gas generator technology. WPAFB provided the engine nacelle simulator located at the Advanced Engine Nacelle test facility. The Engine Nacelle Simulator proved to be a very diverse fixture. Clutter can be simulated in two forms and two engine sizes are available. Internal airflow can be varied easily as well as air temperature. Hot surface re-ignition temperatures of 1300°F can be attained and either JP-8 fuel or 83282 hydraulic fluid used. In summary, this fixture is an outstanding tool for evaluating Halon-1301 and its replacement/alternative agents. Prior to OAC arrival, WPAFB had just completed an L-28 Taguchi test series using Halon-1301 and FM-200 agents. WPAFB chose two Halon-1301 run configurations for OAC gas generator testing.

### RUN NO. 30 RESULTS

The Engine Nacelle Simulator configuration for run no. 30 is illustrated in Figure 18. The test configuration utilized the small engine simulator and 1.25 lbm/sec airflow which represents the lowest air velocity of the two runs. Clutter was in the high simulation mode. Hydraulic fluid (83282) at 100°F with 20 seconds of preburn provided the fuel for the fire located at the top of the simulator. The gas generator discharge location was selected to be at the top of the simulator.

Table 13 presents the test results for the gas generator systems tested. OAC tested a total of 7 gas generator (GG) configurations including:

- Filtered GG
- Nonfiltered GG
- Nonfiltered hybrid H<sub>2</sub>O – 33% hybrid GG (33% of agent weight is H<sub>2</sub>O)
- Filtered hybrid FM-200 – 74% GG (74% of agent weight is FM-200)
- Filtered hybrid PFC-614 – 70% GG (70% of agent weight is PFC-614)
- Nonfiltered hybrid H<sub>2</sub>O – 20% GG (20% of agent weight is H<sub>2</sub>O)
- Nonfiltered hybrid cold fire – 20% GG (20% of agent weight is cold fire)

Testing began with the filtered gas generator with 0.440 lbm of propellant. Beginning with this first test, OAC experienced an unusual phenomenon not previously encountered by the WPAFB personnel. The bulk fire was extinguished by the filtered gas generator; however, several seconds later, the braiding on a thermocouple located in the preburn flame ignited and burned like a candle. No other surfaces ignited although hydraulic fluid was dripping off many surfaces. Convinced that this was an anomaly, OAC halved the propellant load and tested again which did not extinguish the fire. In the third test, the propellant was increased to 0.330 lbm which did extinguish the bulk fire. However, the same thermocouple braid again re-ignited and burned like a candle. Based upon this situation, OAC began to document when the bulk fire was extinguished and when the thermocouple braid re-ignition was suppressed. Table 13 indicates that, in most of the OAC cases, the thermocouple braid reignited despite the fact that the bulk fire was solidly extinguished. It is not clear to OAC if this is a phenomenon associated with the gas generators or if the braiding was just used too many times. In theory, the braiding would act like a wick saturated with fuel. Ignition could occur in the presence of air since the thermocouple wire itself is over 500°F. It appears the phenomenon is nonrepeatable, however. The nonfiltered gas generator extinguished the bulk fire with 0.220 lbm with a thermocouple relight. However, when the propellant weight was increased to 0.330 lbm, the bulk fire was not extinguished.

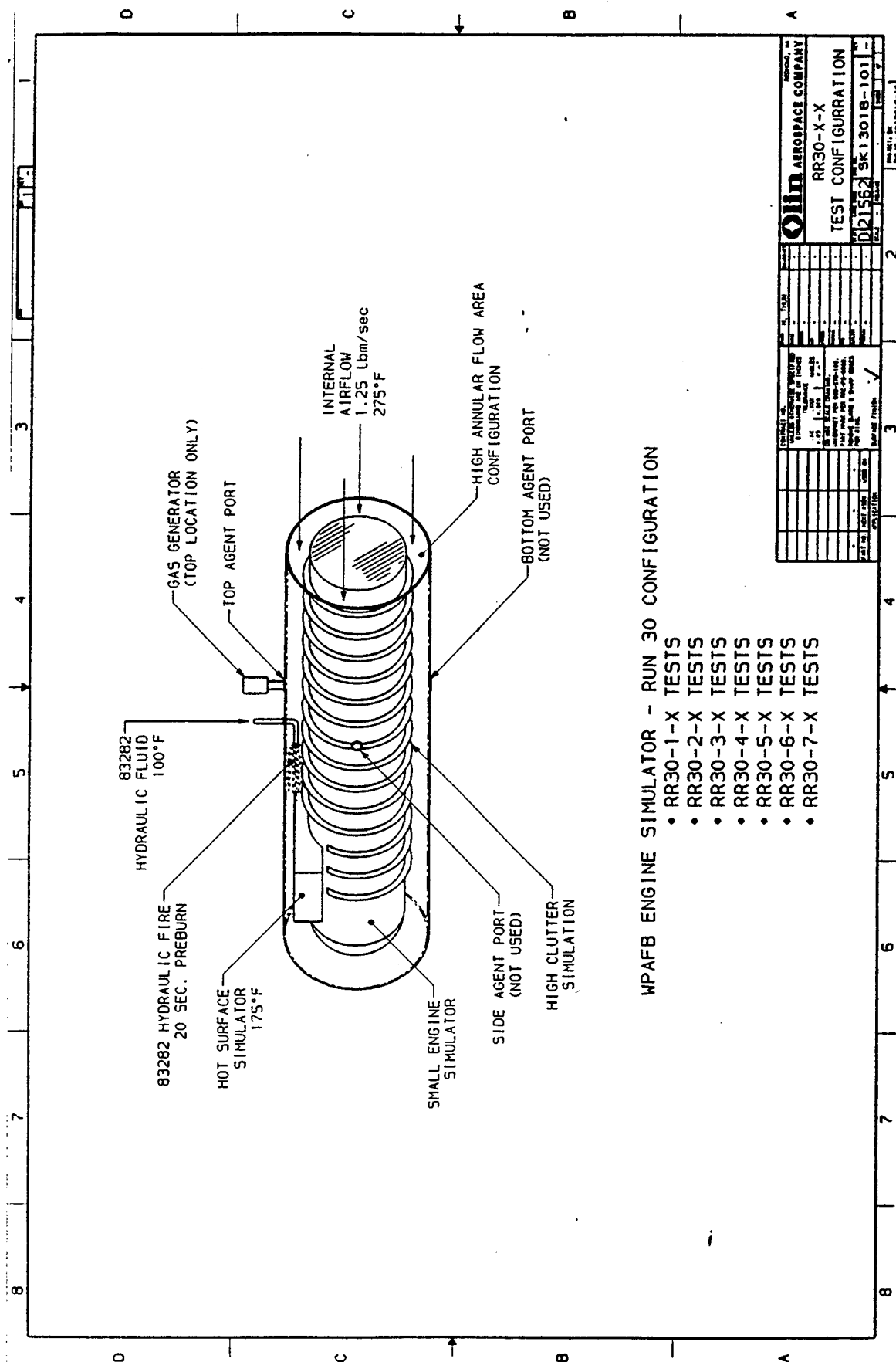


Figure 18  
SK13018-101 - RR30-X-X Test Configuration

Table 13 Phase I Nacelle Fire Suppression  
WPAFB Run No. 30 ①  
Gas Generator Test Results

ym155/9-16-94/74-1

Agent Tested	Test No.	Agent Weight Tested (lbm) ②				Final Weight (lbm)		G.G./1301 Agent Wt. Ratio	
		x = 1	x = 2	x = 3	x = 4	Bulk Fire Suppressed	Thermocouple Re-ignition Suppressed	Bulk Fire Suppressed	Thermocouple Re-ignition Suppressed
H-1301	baseline	0.50	0.25	0.37	0.31	0.280	0.280	NA	NA
Filtered G.G.	RR30-1-X	0.440	0.220	0.330③	—	0.275	0.385	0.98	1.38
Non-filtered G.G.	RR30-2-X	0.440	0.220③	0.330	—	—	0.385	—	1.38
Non-filtered Hybrid H <sub>2</sub> O-33%	RR30-3-X	0.339	0.661③	0.991③	—	0.500	—	1.79	—
Filtered Hybrid FM-200-74% G.G.	RR30-4-X	0.419	0.837	0.558③	—	0.489	0.698	1.75	2.49
Filtered Hybrid PFC-614-70% G.G.	RR30-5-X	0.385	0.771	—	—	—	—	—	—
Non-filtered Hybrid H <sub>2</sub> O-20% G.G.	RR30-6-X	0.551	0.826③	—	—	0.689	—	2.85	—
Non-filtered Hybrid COLDFIRE-20% G.G.	RR30-7-X	0.551	—	—	—	—	—	—	—

Notes:

①

Configuration

- 1.25 lbm/sec airflow @ 275°F
- 83282 hydraulic fluid @ 100°F
- Top fire location, 20 sec. preburn
- 175°F hot surface ignition
- Agent discharge @ TOP port

②

xxx

- bulk fire not extinguished

xxx

- bulk fire extinguished

③

Bulk fire extinguished but thermocouple insulation re-ignited

Final weights for bulk fire suppression and thermocouple re-ignition suppression are provided for each gas generator that was successful. Both the filtered and nonfiltered gas generator performed well compared to Halon-1301. The hybrid gas generator did not perform as expected.

## **RUN NO. 28 RESULTS**

Figure 19 presents the engine nacelle simulator configuration tested. The small engine simulator with an increased airflow of 2.75 lbm/sec was used. High clutter was simulated. The agent discharge part was located on the top while the JP-8 fuel fire was located on the bottom of the simulator.

Table 14 presents the test results of the Halon-1301 and gas generator tested. Due to the schedule constraints, only three gas generator configurations were tested. The nonfiltered gas generator was tested first (RR28-1-X) with the top agent port location as depicted in Figure 19. OAC found that a final value of 3.08 lbm of propellant was required which is 2.74 times the Halon-1301 weight. At this point OAC felt that the distribution of the gas generator was the problem so the side and bottom ports were utilized to see if performance would improve. An additional side port would have been useful to ensure symmetry was attained but the simulator only had one side port. Figure 20 depicts the gas generator locations for test no. RR28-2-X. OAC found that distributing the agent to three ports reduced the final weight by 28%. The final weight for this test was 2.20 lbm or 1.96 times the Halon-1301 weight. With limited time remaining, OAC completed just one additional test which was a nonfiltered hybrid H<sub>2</sub>O-33% gas generator. OAC found that 3.30 lbm of total agent weight would extinguish the fire.

## **PRODUCTION WEIGHTS**

Production weights and volumes are not provided at this time as OAC feels the solid propellant and hybrid gas generators are not close to being optimized yet.

## **CONCLUSIONS**

The thermocouple re-ignitions occurring in WPAFB run no. 30 are quite unfortunate in that the test results become questionable. Clearly, the filtered and nonfiltered gas generators work with 1.38 times the weight of Halon-1301 but the 0.98 weight ratio of the bulk fire extinguished value is more desirable. The fact that all the hybrids performed poorly in run no. 30 suggests that distribution may be an issue.

WPAFB run no. 28 test results indicate just how important distribution is to the gas generator. Clearly, Halon-1301 is a very forgiving agent due to its chemical reacting nature.





Table 14 Phase I Nacelle Fire Suppression  
WPAFB Run No. 28 ①  
Gas Generator Test Results

ym155/9-16-94/T4-2

Agent Tested	Agent Port Location③	Test No.	Agent Weight Tested (lbm)②				Final Weight (lbm)	G.G./1301 Agent Wt. Ratio
			x = 1	x = 2	x = 3	x = 4		
H-1301	Top only	baseline	1.0	2.0	1.5	1.25	1.125	NA
Non-Filtered G.G.	Top only	RR28-1-X	1.76	3.52	2.64	—	3.08	2.74
Non-Filtered G.G.	Top, side and bottom	RR28-2-X	2.64	1.32	1.76	—	2.20	1.96
Non-Filtered Hybrid H <sub>2</sub> O-33% G.G.	Top, side and bottom	RR28-3-X	3.30	—	—	—	<3.30	<2.93

Notes:

①

Configuration

- 2.75 lbm/sec airflow @ 100°F
- JP-8 fuel @ 100°F
- Bottom fire location, 5 sec. preburn
- 175°F hot surface ignition

②

xxx  
xxx

fire not extinguished  
- fire extinguished

③

Baseline agent discharge location is Top port, additional ports tried to distribute G.G. agent more evenly. Only one side port available for use.

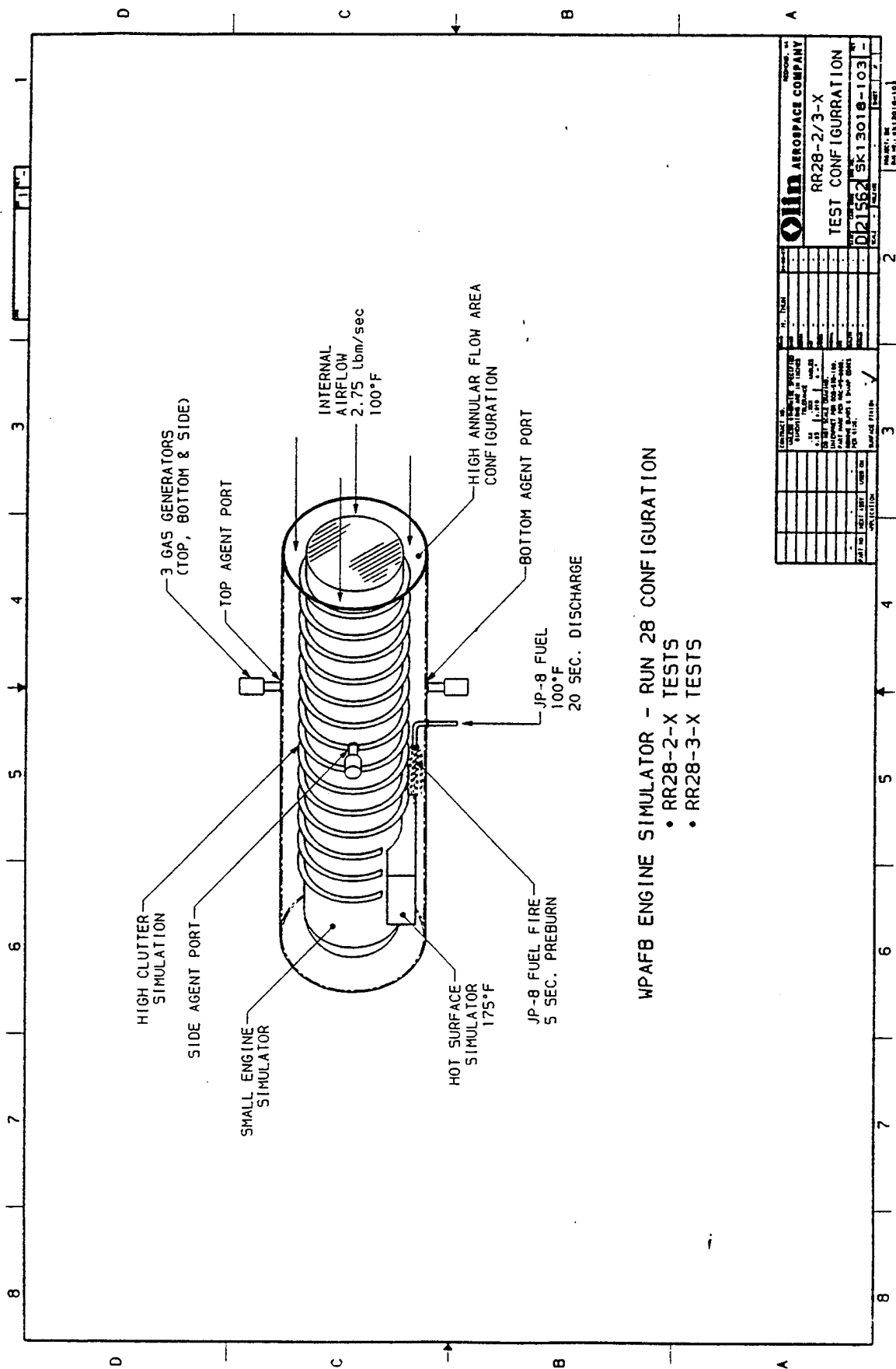


Figure 20  
SK13018-103 - RR28-2/3-X Test Configuration

## **RECOMMENDATIONS**

In February 1995, OAC will return to WPAFB for Phase II Engine Nacelle testing. For run no. 30, OAC recommends that the thermocouple braiding be removed to eliminate re-ignition due to the wicking nature. In addition, OAC plans to reduce the expulsion time of the gas generators and provide a distribution tube which turns the agent and directs it downstream.

For run no. 28, OAC recommends that WPAFB install another side port so the agent can be distributed equally. OAC believes that this change alone will reduce the agent weight by at least 15%. In addition, OAC plans to reduce the expulsion time of the gas generator and provide a distribution tube which turns the agent and directs it downstream.